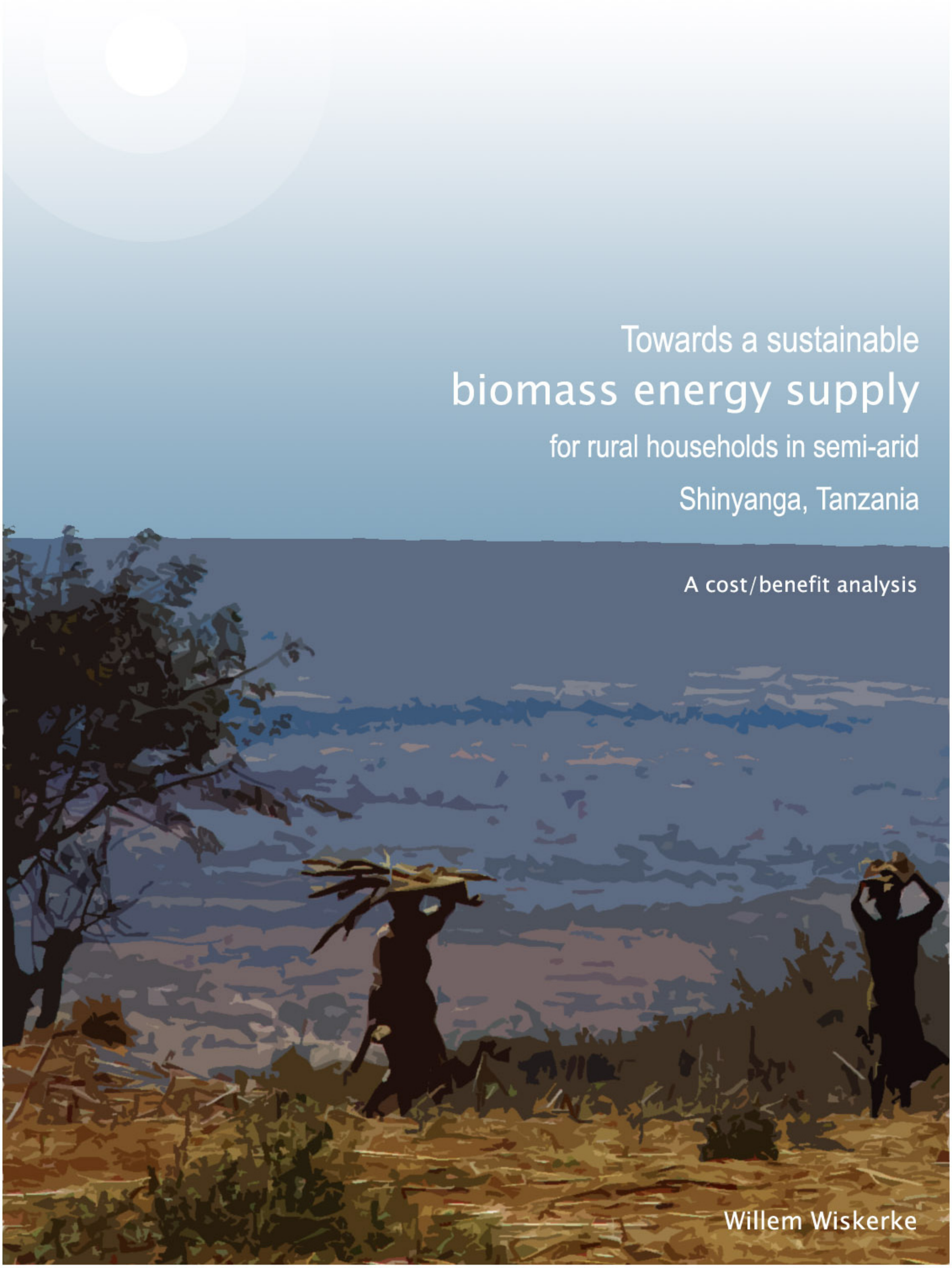

Towards a sustainable biomass energy supply for rural households in semi-arid Shinyanga, Tanzania

A cost/benefit analysis

Willem Wiskerke

Universiteit Utrecht

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Abbreviations

CDM	Clean Development Mechanism
CER	Certified Emission Reduction
COE	Cost of Energy
CO_2	Carbon dioxide
dm	Dry matter (zero moisture content)
€	Euro
GDP	Gross Domestic Product
GJ	Giga Joule (10^9 Joule)
GJ_H	Giga Joule heat
ha	Hectare
IEA	International Energy Agency
kg	Kilogram
ktonne	Kilotonne (1.000.000 kg)
kWh	Kilo Watt hours ($3.6*10^6$ Joule)
lCER	Long-term Certified Emission Reduction
MAI	Mean Annual Increment
MJ	Mega Joule (10^6 Joule)
NPV	Net Present Value
PJ	Peta Joule (10^{15} Joule)
PPP	Purchasing Power Parity
tCER	Short-term Certified Emission Reduction
Tsh	Tanzanian Shilling
TANESCO	Tanzania National Electricity Supply Company
US$	United States Dollars
VAT	Value Added Tax
VER	Voluntary Emission Reduction

Summary

Aim of the research

This study aims to analyze and compare the costs and benefits of three alternative sustainable biomass energy supply systems for rural households in a semi-arid region in a developing country. Thereby, the main opportunity costs and optional benefits of each system are included and an uncertainty analysis is carried out. Shinyanga region in Tanzania was chosen as a case study. The following systems were analyzed:

1. A small-scale forestation project for carbon sequestration under the Clean Development Mechanism (CDM) of the Kyoto Protocol or on the voluntary carbon market, which at the same time can be a sustainable source of fuelwood for a local community.
2. A short rotation woodlot for the production of fuelwood or charcoal, optionally with intercropping.
3. A *Jatropha curcas L.* plantation. The yielded Jatropha oil can be used as a cooking fuel, it can be traded, used as a diesel substitute for off-grid household electrification or it can be used as an ingredient for soap production.

Research context

Traditional biomass accounts for 92% of the Tanzanian energy supply and consists mainly of fuelwood and charcoal (IEA 2008). Charcoal is mostly consumed in urban areas, while rural areas depend almost completely on fuelwood. Per capita fuelwood consumption varies significantly per region, depending on the woody biomass density. In semi-arid areas with a low woody biomass cover, the annual consumption is lower as the demand, resulting in a fuelwood deficit, or energy poverty. Fuelwood collecting is a task traditionally executed by women and the burden of collecting can be considerable, both in terms of time and effort. Contradictive to the heavy burden of collecting, fuelwood is mostly burned on three stone stoves with an energy efficiency of 7-12% (Kaale 2005). As an intermediate step towards modern energy provision, small-scale sustainable biomass energy production is desirable.

In the past, the natural woodland cover in semi-arid Shinyanga has been massively cleared for the expansion of livestock and agriculture, leading to severe land degradation. Today, Shinyanga is characterised by huge livestock populations. The Sukuma tribe, who are agro-pastoralists, make up 80% of the population, and livestock holding is playing a central role in meeting their social and economic needs (Mlenge 2004). Furthermore, the population is rapidly growing, at a rate of 3.3% annually (OXFAM 2007). Because of low soil fertility, poor rainfall, low fertilizer input and poor traditional management, food crop yields in Shinyanga are low, about 8 times lower compared to industrialized countries (HASHI 1998; CIMMYT 2000), resulting in low labour productivity and increased poverty.

Methodology

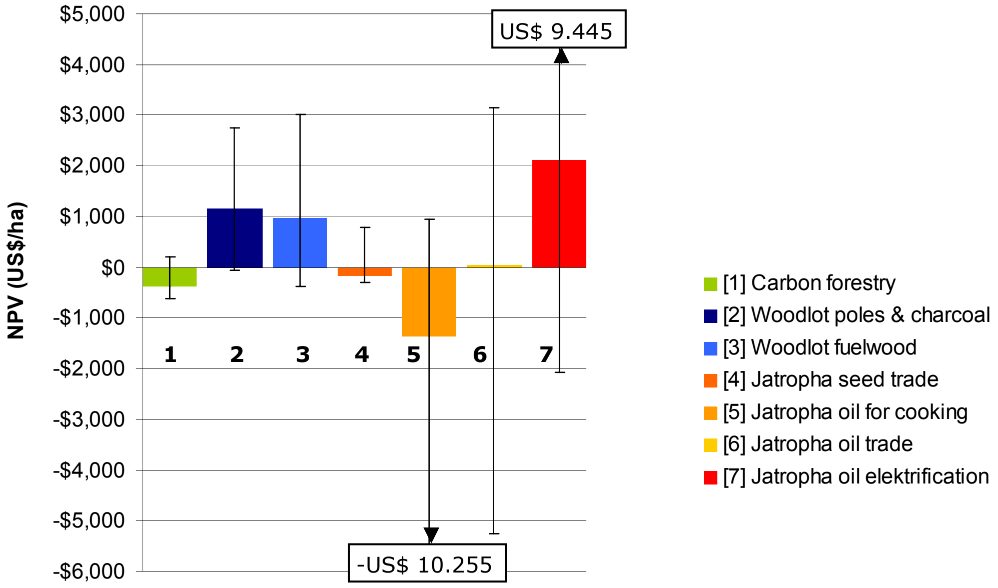
First, the baseline situation was assessed. This was translated to the economic parameters of the opportunity cost of land, the shadow cost of labour, the return on labour, the cost of energy and the cost of utilized heat for cooking. The opportunity cost of land was assumed to equal the renting price of agricultural land during the wet season and grazing land during the dry season. Based on the economics of maize cultivation in Shinyanga, complemented with literature and expert estimates, the shadow cost of labour was determined to be Tsh 1.722, or US$ 1,43, per man-day. When combining the opportunity cost of land and the shadow cost of labour, the baseline return on labour for maize cultivation was determined to be Tsh 2.265, or US$ 1,88, per man-day. The NPV of maize cultivation was thus used as a baseline and defined as zero, compared to the systems. The cost of primary energy was determined for various alternatives: Fuelwood, charcoal, kerosene and off-grid electricity. By including the costs and efficiencies of various cooking stoves, the cost of utilized heat was determined. The latter varied from as low as US$ 7,27 per GJ_H on an improved fuelwood stove to as high as US$ 79,49 per GJ_H on a kerosene stove. Next, the economic feasibility of the three biomass energy supply systems was determined based on the Net Present Value per hectare, the Return on labour and the Cost of energy, applying a real discount rate of 11.8% (Bank of Tanzania 2008). The impact of the main input parameters on the results was analyzed by means of sensitivity analyses.

Carbon forestry is assumed to be initiated by an external project developer on general land that is presently used for grazing. 10% of the annual biomass increment is reserved for fuelwood harvesting by a local community. This community can further benefit from other forest products, including fodder, since livestock is allowed in the carbon forest. For the project developer, the project is only feasible when the discounted benefits of trading carbon credits outweigh the discounted forestation and transaction costs. For trading carbon credits under the Clean Development Mechanism (CDM), a simplified small-scale forestation methodology was applied. Therefore, the annual CO_2 mitigation may not exceed 8 ktonne. Furthermore, only temporary carbon credits can be obtained for forestation projects. On the voluntary carbon market, these constraints do not apply. However, for comparison a methodology that yields similar quality carbon credits was applied.

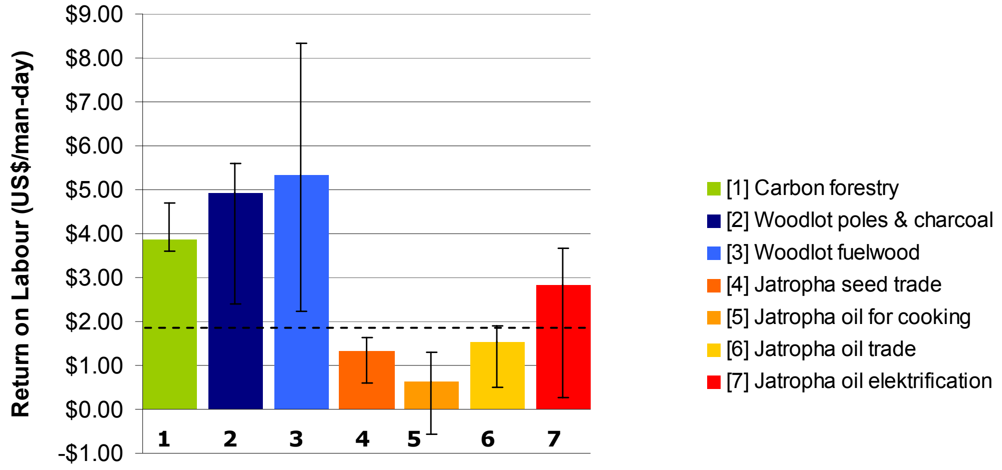
The economic feasibility of rotational woodlots is based on the results of an experiment in Shinyanga described by Nyadzi *et al*. (2003), in which *Acacia Polyacantha* is intercropped with maize on smallholder land. The opportunity of producing fuelwood, charcoal and poles is included in this analysis, even as the burden of government taxes. Jatropha oil is produced by manual oil extraction of the picked seeds, using a small ram press. The options of seed trading, oil trading, cooking, soap production and rural electrification are included in the analysis. For the latter, the NPV per hectare and the Return on labour, relative to using conventional diesel for an electrification project is determined.

Results

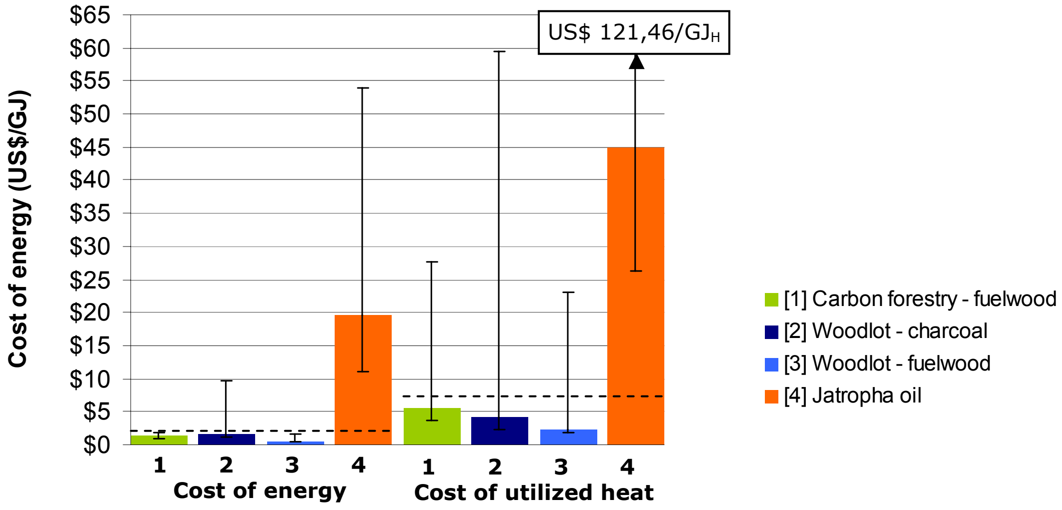
In the following graphs, the Net Present Value per hectare, the Return on labour and the Cost of energy are compared for the various systems. The error bars are based on uncertainty in the main input parameters, namely the shadow cost of labour, the discount rate, the fuelwood market price, the mean annual growth increment, the CER market price, the charcoal kiln efficiency, the Jatropha seed yield and the Jatropha plantation size.



S1: System comparison of the NPV per hectare, including error bars. Woodlots are with intercropping. The baseline NPV of maize cultivation is defined as zero, compared to these systems.



S2: System comparison of the Return on labour. The dashed line indicates the baseline Return on labour of a maize-fallow system.



S3: System comparison of the Cost of energy and the Cost of utilized heat for household cooking, when applying best practise cooking efficiency. The dashed lines indicate the baseline average cost of fuelwood of Tsh 600 per headload.

Local fuelwood supply by means of a carbon forestry project is not economically feasible in semi-arid Shinyanga. The estimated annual above-ground biomass increment of 2 tonne dm/ha/year is too low and risks of fire are too high so that the specific costs per hectare are larger as the benefits of carbon trade per hectare. Trading temporary carbon credits under the CDM is found to be more attractive compared to trading voluntary carbon credits. The lower transaction costs on the voluntary market are outweighed by a higher market price for carbon credits under the CDM. To mitigate 8 ktonne of CO_2 annually, 1558 ha of woodland is needed. About 50% of the forestation costs can be covered by carbon trade, leaving a gap of about US$ 400.000, or US$ 261 per hectare, in terms of NPV. However, the error margins based on uncertainty in the main input parameters are large. Furthermore, this is the NPV for the project developer/investor. It does not include the forest benefits experienced by a local community and the indirect benefits of combating land degradation. Such forest benefits for a local community can be significant, as indicated by Monela *et al*. (2005). Based on these benefits, donor organizations might be willing to finance the gap in the NPV of carbon forestry. The Return on labour consists mainly of the Tanzanian minimum wage rate paid to the land workers. The cost of energy of US$ 1,46 per GJ consists of the carbon benefits foregone by harvesting fuelwood and the cost of harvesting.

When government fees on wood production are excluded, rotational woodlots are highly economical in semi-arid Shinyanga. The NPV is maximized to US$ 1.165 per hectare when producing poles from stem wood and charcoal from branches, while practising intercropping of maize. However, the Return on labour is maximized to a value of Tsh 8.387, or US$ 6,96 per man-day when producing poles and fuelwood on a monoculture woodlot, since this has the lowest labour intensity. Thus, a farmer who is constraint by land and wishes to maximize added value per unit of land is better of by producing poles and charcoal and applying intercropping, while a farmer who is constraint by labour and wishes to maximize his/her return on labour is better of by producing poles and fuelwood from a monoculture. Of course, these options can be further constraint by market access. The woodfuel production cost price is determined to be Tsh 163 per headload (US$ 0,53/GJ) and Tsh 1.914 per bag (US$ 1,71/GJ) for fuelwood and charcoal, respectively, which is under the baseline cost of Tsh 600 per headload and Tsh 5.000 per bag of charcoal (farm-gate price). When applying best practise cooking efficiency and a kiln efficiency of 30%, heat production per hectare is about equal for fuelwood and charcoal, since charcoal has a higher end-use energy efficiency. However, the error margins related to uncertainty in the input data is rather large. When the government fees on wood production from woodlots are included, the economic profitability quickly diminishes. When producing fuelwood or charcoal from a 1 hectare woodlot, the total tax burden erases all potential profits. This is mainly caused by the annual government license of Tsh 200.000, which is independent of the woodlot size. This tax system on sustainable produced woodfuel contradicts with the government policy on combating deforestation and energy poverty, since it blocks dissemination of smallholder woodlots.

The Jatropha seed production potential in Tanzania is still highly uncertain. No data could be found on the expected average seed yield in semi-arid Shinyanga. Based on an expert estimates, a productivity of 2 kg seed per shrub per year, reached in year 9 was estimated. The production cost of Jatropha seed from a 1 hectare plantation is determined to be Tsh 118 per kg, or US$ 97,55 per tonne. The production cost of oil is determined to be US$ 0,73 per litre, or US$ 19,60 per GJ. The labour intensity of seed picking and manual oil expelling is large and accounts for 56% of the oil production costs, making the production cost sensitive towards the shadow cost of labour. Because of the high labour intensity per unit of added value, the returns on labour for Jatropha-based systems are below the baseline of maize cultivation. However, the high uncertainty in input parameters, mainly the expected seed yield and the shadow cost of labour, result in wide error ranges for both the NPV and the cost of energy. Jatropha oil is too expensive for utilization as an alternative cooking fuel. It is better suited as a blend in local diesel engines, since the production cost is 49% of the market price of diesel in rural Shinyanga. Even though, there is no market yet, a market price of US$ 0,75 per litre for Jatropha oil as a diesel blend was estimated. Furthermore, Jatropha oil can be used as an alternative to diesel in rural electrification projects. 1 ha of Jatropha plantation yields about 31 GJ of primary energy per year. When utilizing this for small-scale electricity production using an adapted generator, the production cost of electricity becomes US$ 0,60 per kWh, compared to US$ 0,79 per kWh when using diesel. Such high prices are not affordable for the average consumer; however scaling-up will reduce the electricity cost. Furthermore, subsidized off-grid electrification projects, executed by TANESCO, could also benefit from relatively cheap locally produced Jatropha oil. For the production of biodiesel, Jatropha oil has to be processed by means of transesterification. This is a capital intensive process that is only feasible when Jatropha oil production is further scaled up and a larger market is created. Utilizing Jatropha oil for soap production is very profitable for smallholders, although this is still a niche market.

Conclusions

From a smallholder perspective rotational woodlots are preferable for maximizing income and producing low-cost household energy. Jatropha oil is only economical as a local diesel substitute or as an ingredient for soap production. From a government perspective, the positive socio-economic and ecological effects of carbon forestry might compensate for the financial gap between costs and benefits, caused by the low growth increment in semi-arid Shinyanga.

Recommendations

- The government fees on fuelwood and charcoal production should be lifted for sustainable fuelwood and charcoal, produced on smallholder land.
- Distribution of knowledge about rotational woodlots and tree seedling distribution amongst farmers should be further increased.
- Research on tree performance, as carried out by the NACRAF institute in Shinyanga, should be enhanced and if possible scaled-up.
- Research is needed on the local socio-economic benefits of carbon forestry.
- Research is needed on the economic benefits of vegetation fodder and leguminous fodder.
- Research is needed on the seed yield of Jatropha in semi-arid Shinyanga under different soil qualities.
- To better determine the economic feasibility, more research is needed on the labour intensity of Jatropha oil production.

1. Introduction

In the developed world, problems related to sustainable energy are widely associated with the problem of climate change and the need for significant greenhouse gas emission reductions. However, there is another worldwide energy problem, which is somewhat more hidden and mainly taking place in developing countries. It is the fact that the poorest in these countries often face a serious lack of energy resources and depend on unsustainable and relatively low-quality biomass energy sources for their subsistence.

Traditional biomass is the main energy source in many developing countries. Today, traditional biomass still provides 60-90% of the energy demand in de world's poorest countries. In absolute terms, the use of traditional bio-energy continues to grow due to a rapid population increase in many developing countries, increasing demand and a lack of accessible and affordable alternatives (Rosillo-Calle *et al.* 2007). Fossil fuels are mostly unaffordable and grid-connection is often absent for rural communities. This situation is only expected to become worse with the current trend of rising fuel prices, which affects these countries significantly more than developed countries (Del Greco *et al.* 2005). The main traditional biomass source is wood, which is burned directly, or transformed into charcoal. Charcoal production and trade is a major economic activity in many developing countries and millions of people depend on it for their subsistence (Rosillo-Calle *et al.* 2007). Additionally, agricultural residues and animal manure are utilized. For many, this combination barely allows fulfilment of the basic human needs of food preparation, warmth and light, let alone the possibility of using energy for production of goods, which might be a way to escape from the cycle of poverty (Del Greco *et al.* 2005).

One of the major problems of current patterns of traditional fuelwood in developing countries is the low conversion efficiency. In households, most fuelwood is burnt with an average conversion rate of 7-12% (Kaale 2005) and charcoal is produced in kilns with an efficiency of 11–19% (Malimbwi *et al.* 2007). These efficiencies have not changed for centuries, because charcoal production and use is mainly an activity of the poor who are struggling to survive (Rosillo-Calle *et al.* 2007). Related to this, indoor air pollution caused by the burning of wood and charcoal, poses a major burden on the health of, especially women and children in developing countries. It is estimated that 1.6 million people die every year from diseases caused by indoor air pollution (WHO 2005). Furthermore, women are forced to spend considerable time and effort collecting fuelwood for the household.

The need for traditional biomass energy places a high burden on forest resources in many developing countries. It is estimated that worldwide 2 billion tonnes of wood go up in smoke every day for cooking, heating or charcoal production (WHO 2006). While, forest clearing for agricultural expansion, shifting agriculture and livestock are the main drivers, unsustainable consumption of fuelwood is still an important driver for forest degradation and deforestation in many developing countries (FAO 2003; FAO 2004; Mbwambo 2004). Deforestation leads to severe degradation of soils. Degraded soils have lost significant amounts of soil carbon. Soil degradation is especially a problem in the world's drylands, which cover up 47% of the land surface of the world, mostly in developing countries (FAO 2004). Additionally, within these drylands, soil degradation predominantly affects semi-arid areas, where most agricultural cultivation and pastoral activities take place, resulting in decreasing agricultural production. Smallholders that live on semi-arid areas in developing countries are mostly poor and forced to focus on pursuing basic subsistence and survival goals; land degradation adds another burden to their existence (FAO, 2004). In addition, as land pressure increases due to the strong population growth in developing countries, more and more marginal areas in the world are being used for agriculture. Much of this land is located in the arid or semi-arid belts (Mbwambo 2004). To combat the downward spiral of poverty, deforestation and land degradation, rural communities should be provided with more sustainable energy sources. Furthermore, such sustainable energy sources might as well improve local livelihoods by increasing the daily energy supply (Del Greco *et al.* 2005; Monela *et al.* 2005) and reducing respiratory diseases. Although there has been a lot of discussion on the wood energy crisis, including its environmental consequences, there are major gaps in information on the demand and supply of fuelwood (FAO 2003).

Africa is the world's poorest continent and besides that, Africa is the continent with the highest population growth in the world, which is estimated to be 3.5% per year. This leads to an increasing burden on the natural resource base and increasing rates of land degradation; on a continent where people are mostly depending on small-scale agriculture for their subsistence (UNEP 2006). Within Sub-Saharan Africa, Tanzania has about an average economic performance with an estimated average GDP of US$ 744 per capita (PPP adjusted) (UNDP 2008). Agriculture is the foundation of the Tanzanian economy, which is dominated by smallholder farmers. About 80% of the population of Tanzania lives in rural areas (Mbwambo 2004). About 30% of the land surface area of Tanzania can be classified as semi-arid (FAO 2008). With an average annual rainfall of 600 mm per year, the eastern part of Shinyanga region is part of the vast semi-arid area in central Tanzania (Monela *et al.* 2005). This region has been prone to severe deforestation and land degradation. However, successful government intervention, based on promoting natural regeneration of woodlands has led to significant improvement of the situation since the 1980's (Kaale *et al.* 1985; Mlenge 2004; Monela *et al.* 2005). Unlike this success, semi-arid Shinyanga is still faced with a fuelwood deficit (FAO 2005b).

The gap between the present energy situation in East Shinyanga and a modern energy grid is rather big. As an intermediate step towards modern energy provision, small-scale sustainable biomass energy production is desirable. There are several ways to accomplish such provision; however, there are serious economic constraints towards implementation, since people are generally poor and have limited or no assets to invest. In Tanzania agroforestry is well-recognized as a technology that can significantly improve the rural energy situation and some research has been done on the economics of small-scale woodlots for fuelwood production in Tanzania (Kihiyo 1996; Ramadhani *et al.* 2001). These studies both conclude that woodlots have significant economic benefits for smallholders. Alternatively, charcoal can be produced. The economics of charcoal production in Tanzania has been studied by Malimbwi (Malimbwi et al. 2000). Planting forest for carbon mitigation could provide income for local communities and at the same time provide a sustainable source of fuelwood. Limited theoretical research has been carried out on the costs and benefits of small-scale forestation projects for carbon trading (Michaelowa *et al.* 2003; Locatelli *et al.* 2006; Cacho *et al.* 2007; Neeff *et al.* 2007) and case studies on this issue could not be found. At last, wood could optionally be replaced by a different energy carrier, like plant oil from the shrub Jatropha *curcas L.* On Jatropha oil production, limited literature on costs and benefits could be found (Openshaw 2000; Henning 2003; Del Greco *et al.* 2005; van Eijck 2007b). However, the general focus in these studies is on utilizing the oil as a biofuel, none of these studies focuses on the utilization of Jatropha oil as a household cooking fuel.

This study aims to analyze and compare the costs, benefits and risks of three different sustainable biomass energy supply systems in semi-arid regions in developing countries, using East Shinyanga as a case study area. The following systems will be analyzed:

4. A small-scale forestation project for carbon sequestration under the Clean Development Mechanism (CDM) of the Kyoto Protocol or on the voluntary carbon market, which can be a sustainable source of fuelwood.
5. A short rotation woodlot for the sustainable production of fuelwood and/or charcoal.
6. A Jatropha plantation, thereby using the yielded Jatropha oil to substitute fuelwood as a cooking fuel. Additionally, Jatropha oil can be used as a diesel substitute for off-grid household electrification.

In addition, a comparative analysis of different small-scale, sustainable biomass energy production systems in developing countries seems absent in present literature. Furthermore, it seems that the role of opportunity costs of the produced energy carriers is not sufficiently analyzed in the literature covering bio-energy systems in Tanzania. Yet, this is a rather important factor for determining the success of a project: When a smallholder can maximize his profit by selling the produced stem wood from a rotational woodlot as poles, instead of producing fuelwood, he/she is likely to do so. A comparative cost/benefit analysis (CBA) that takes all opportunity costs into account would be useful for determining the most cost-effective and realistic biomass energy supply system for reducing energy poverty and forest degradation in developing countries, while at the same time such a study can give insight in the economics and risks of the supply and demand of traditional biomass energy. This research aims to partially fill this gap. The research objective is defined as follows:

> *To analyze and compare the economic feasibility and the socio-economic impacts of three different sustainable small-scale biomass energy supply systems for rural smallholders in the semi-arid eastern part of Shinyanga region, Tanzania, by conducting a cost/benefit analysis.*

The research questions are defined as follows:

A. *What is the economic feasibility of the three small-scale biomass energy supply systems in East Shinyanga?*

B. *Which factors have the largest influence on the economic feasibility of these systems?*

C. *What are the potential socio-economic impacts of these biomass energy systems on rural smallholders?*

D. *Which of these systems is preferable from a socio-economic point of view?*

Chapter 2 will provide relevant background information on Tanzania and on East Shinyanga in more detail. Besides geographic and socio-economic characteristics, the energy situation and problems related to deforestation and land degradation will be looked at, as well as government policies to tackle these problems. In chapter 3, the proposed biomass energy supply systems will be further explained. General CBA methodology that is applied is explained in chapter 4. Furthermore, the baseline is defined, even as the applied methodology to determine the costs and benefits of the three systems. In Chapter 5 the collected input data is listed and in chapter 6 the results of this analysis are presented. Finally, the results are synthesized and discussed and conclusions are drawn.

2. Study background

2.1 Tanzania

2.1.1 Geography

Tanzania is situated at the east coast of the African continent, bordered by Kenya, Uganda, Rwanda, Burundi, Congo, Zambia, Malawi and Mozambique. It has a total area of 945.000 km^2, of which 2.450 km^2 are on the Zanzibar archipelago and 885.000 km^2 is land area, making it the 9th largest country in Sub-Saharan Africa, equivalent to 1.7 times the size of France (WFP 2006). Tanzania has a spectacular landscape of mainly three physiographic regions namely the islands and the coastal plains to the east, the inland plateau and the highlands. Two-third of the land area is dominated by highland plateau, of which the semi-arid central plateau has an average altitude of 1.200 m (WFP 2006). These vast plains and plateaus contrast with spectacular physical features: In the north, Mount Kilimanjaro rises to 5.895 m, the highest peak on the African continent, while in the west, Lake Tanganyika is the World’s second deepest lake (1.436 m). The East African Rift Valley, part of the Great Rift Valley, runs north-south leaving many narrow, deep depressions, often filled with lakes (Tanzania 2008).

Figure 1: Map of Tanzania with Shinyanga region highlighted.

2.1.2 Climate

The climate varies from tropical with relatively high humidity along the coast to arid and semi-arid on the Central plateau, receiving less than 500 mm of rain annually. In contrast, the mountainous areas in the north-east and south-west receive over 2.000 mm of rain annually (WFP 2006). Two rainfall regimes exist over Tanzania. A unimodal regime is experienced in the southern, south-west, central and western parts of the country, where the rain season lasts from December to April. In the north and along the coast, there is a bimodal rainfall pattern with short rains from October to December and long rains from March to May (Tanzania 2008). Although overall well watered, the rains are poorly distributed and the country experiences a long dry season from May to November (WFP 2006). Additionally, the rainfall is rather unreliable, adding another constraint to agriculture. The definition of semi-arid areas in Tanzania is acknowledged to be problematic and several definitions are in use (Schechambo *et al.* 1999; Morris *et al.* 2002). Not only is the annual rainfall of importance, but also evapotranspiration and rainfall distribution. The FAO defines agro-ecological zones according to the Length of Growing Period (LGP), which is 75-179 days per year for a semi-arid zone (FAO 2004). According to this definition, 30% of the land surface of Tanzania can be classified as semi-arid (FAO 2008), including east Shinyanga.

2.1.3 Natural resources

Tanzania is world-famous for its national parks and game. Nearly 25% of Tanzania's land area is protected nature reserve (MNRT 1998). Furthermore, it has about 33.55 million hectares of forests and woodlands, which is 38% of the total land surface (MNRT 1998). More than 90% of Tanzania's forested area is covered by savanna woodlands. The woodlands show a varying degree of tree cover, and many terms are used to make distinctions, such as 'closed woodlands', 'open woodlands' and 'wooded grasslands'. A common term for most woodlands is *Miombo* woodlands. *Miombo* is a name used by the Wanyamwezi people for the *Brachystegia* trees that are very common in these woodlands, often being co-dominant with species such as *Julbernardia* and *Acacia* (Chitiki *et al.* 2007). 43% of the forested land is designated as protected forest reserve, while the remaining 57% is public forest (Malimbwi *et al.* 2000).

Over the period 2000-2005, 412.000 ha of forest have been removed annually on average. This is 1.1% of the forest cover per year in relative terms (FAO 2005a). However, the Tanzanian government is estimating the annual deforestation at 91.000 ha per year (TAFORI 2005). The main reasons for deforestation are clearing for agriculture, overgrazing, wildfires, charcoal-burning and over-exploitation of wood resources. Deforestation is mainly taking place in the public forests, but due to increasing population pressure and inadequate resources for forest management it is also occurring in forest reserves (MNRT 1998).

Forestation projects have proven to be important tools to combat the negative trend of deforestation and land degradation in Tanzania. Forestation activities can take many shapes, depending on the main goals they aim at. Trees prevent soil erosion and can be a sustainable source of fuelwood, timber, fruits, nuts, honey, medicine, fodder, etc. for local communities (ICRAF-ECA 2003). Furthermore, forestation projects can be initiated to restore natural ecosystems and biodiversity. In Tanzania, tree planting programs and campaigns date back to the 1960's as part a of nation wide forestation effort (Skutsch 1983; Mbwambo 2004). Furthermore, the government is allocating public forest land to villages in order to avoid uncontrolled use (MNRT 1998).

2.1.4 Socio-economics

In 2006 Tanzania had a population of about 39.5 million people and an average population growth of 2.6% (World Bank 2008). The far majority of the population (77%) is living in rural areas (Tanzania 2005), while Dar es Salaam, at the east coast, is by far the largest city with an estimated population of 2.8 million people (NBS 2006). Tanzania is one of the poorest countries in the world with an estimated average GDP of US$ 744 per capita (PPP adjusted) (UNDP 2008). In 2002, 35.7% of the population was living below the national basic needs poverty line and 18.7% below the food poverty line. Poverty remains overwhelmingly in rural areas and is highest among households that depend on agriculture (Tanzania 2005). However, socio-economic indicators show positive trends in Tanzania. Poverty is declining and school enrolment is increasing all over the country, though, faster in urban areas. Tanzania's recent economic growth rate has been impressive, with an average rate of 6.5% and an inflation rate of 4.8% over the last 6 years (Bank of Tanzania 2008). The national currency of Tanzania is the Tanzanian Shilling (Tsh)*. Agriculture is the foundation of the Tanzanian economy; it accounts for 45% of the GDP and is dominated by smallholder farmers. The agricultural sector has grown 3% on average over the last decade. However, this growth is almost completely compensated by the population growth (MAFC 2001). Primary export crops are coffee, cotton, cashew nut, tobacco, tea, sisal and pyrethrum. Maize, cassava, rice, bananas and wheat are grown for local consumption (WFP 2006). Especially maize is produced extensively, since it is the main ingredient for *ugali*, a porridge or dough, which is the most preferred food in Tanzania. In 1999, maize was grown on about 45% of total arable land and 75% was consumed on the farm (Limbu 1999).

Staple crop yields in Sub-Saharan Africa are the lowest in the world. The average maize yield in Tanzania over the period 1996–2003 was 1.33 tonne/ha (MAFC 2008), compared to 8 tonne/ha in industrialized countries (CIMMYT 2000). The use of modern agricultural technology is not a common practice in Tanzania and as a result, agriculture in Tanzania is still underdeveloped. Still, the large majority of smallholders are depending on the hand hoe for cultivation and weeding, which is rather labour intensive and results in serious labour constraints. Out of every ten farmers, only three use improved seeds, only four use animal manure for fertilization, and only two use chemical fertilizers (Limbu 1999).

Consequently, The agricultural sector is the main employer, with 78% of women and 71% of men in agricultural occupations (NBS 2005). Measurement of unemployment in Tanzania is far from simple, since especially in rural areas, many people are part of an informal agricultural economy, which is strongly seasonal and based on subsistence farming. As a result, under-employment occurs mainly in rural areas when people have no work during the agricultural off-season, which is the dry season. Formal wage employment constitutes only a small proportion of total employment. The official unemployment rate stands at 12.9%, but is relatively higher in urban areas. On the other hand, average labour productivity and incomes are lower in rural areas. In the Tanzanian economy, child labour is prevalent and worst in rural areas and again, especially in the agricultural sector (Tanzania 2005).

Women are arguably the backbone of the Tanzanian rural economy. The heavy burden of household labour is currently borne disproportionately by women (Tanzania 2005). In contrast, women often do not have control over productive assets, like land or cash. While both men and women have an equal share in the workload of agricultural activities, resources generated from these activities are predominantly managed by the male head of the household, despite equal participation (WFP 2006). According to the 2004/05 Household Budget Survey, 92.5% of the women working in the agricultural sector are not self-employed and 77.8% are not paid (NBS 2005).

2.1.5. Politics and land tenure

Many facets of society and economy in contemporary Tanzania cannot be properly understood without reference to the country's post-independence history (Ellis et al. 2003). After its independence from colonial power in 1961, Tanzania adopted socialism and the country was ruled by a single party under the leadership of Dr. Julius Nyerere, to whom Tanzanian still refer to as *Mwalimu*: The Teacher. Nyerere implemented a policy of unification (*Ujamaa*), which included enforced villagisation of previously scattered farm homesteads in the rural economy, the adoption of *Swahili* as a national language, control on agricultural prices and

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[*] 1 Euro = 1667 Tsh, 1 US$ = 1205 Tsh (Average over 2007). Source: Oanda 2008.

markets and nationalization of agricultural estates, industries and the service sector (Ellis *et al.* 2003). Looking back, this policy led to economic failure (WFP 2006); however the promotion of a Tanzanian identity brought peace and stability to a country that is made up of 120 different tribes. Since its independence, Tanzania never experienced serious ethnic conflicts or civil war, in contrast with all its surrounding neighbours. In 1995, the first multi-party elections were held, but the ruling party *Chama Cha Mapinduzi (CCM)* always kept a large majority. Tanzania is organized on four different levels: The National Government, the Regional Government, the District Council and the Village Government. The latter is empowered to issue so-called village by-laws on all village matters. These local laws on land tenure, social justice, etc., are not jurisprudential, but can be applied in the village environment under customary law.

The dual system of land tenure introduced by the colonial regime has been maintained by the Tanzanian government: All land in Tanzania is public land, meaning that it is owned by the central government (MLHUD 1994). However, right of occupancy, which is the main form of tenure, can either be acquired through a grant by the Commissioner for Lands, *or* through local customs and traditions (LEAT 2008). The forced villagization of 1974–1976 led to massive expropriation of existing customary land tenure and land had to be re-divided. Afterwards, villages were provided with communal land and households were granted land within the village boundaries by contract, which they may occupy for cultivation for a period of up to 99 years. These contracts are inheritable but rural dwellers do not own the land and the land can not be traded (Mlenge 2004). Foreign investors can obtain a title deed to use so-called general land from the government for an annual land lease fee. This is often residual land that is not village land nor nature reserve. However, such land can still be used under customary land tenure, like grazing land for cattle (MLHUD 1994; Mwamhanga 2007). In recent history, the government is adopting a policy towards privatization of land in order to increase local responsibility for land use, attract foreign investors and to decrease land conflicts and exploitation of natural resources (MLHUD 1994).

2.1.6 Energy supply and demand

In 2005, Tanzania had a Total Primary Energy Supply (TPES) of 854 PJ, or 22.2 GJ per capita. For comparison, this is 10.6% of the per capita primary energy supply in the Netherlands (IEA 2007). Compared to other continents, Africa has the highest per capita woodfuel consumption (EC-FAO 1999). Woodfuel, as opposed to fuelwood, includes all woody biomass energy sources, basically charcoal and wood. Obviously, Tanzania is leaning heavily on traditional biomass resources for its energy demand as well, as can be seen in Figure 2:

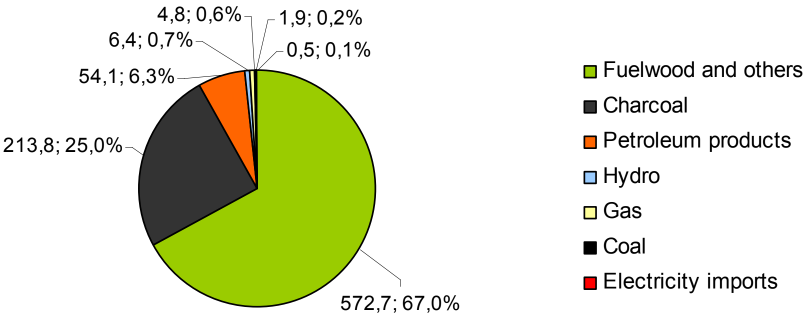

Figure 2: Total Primary Energy Supply (TPES) of Tanzania in 2005 in PJ. Source: (IEA 2008). '*Other transformation*' of '*Combustible renewables and Waste*' in the IEA Energy Balance is allocated to charcoal production, using a kiln energy efficiency of 33% (Malimbwi *et al.* 2007). 'Others' consist mainly of crop residues and animal manure. It is not known to what extend these contribute to the overall traditional biomass consumption, but their contribution is regarded as only a small fraction.

2.1.6.1 Fuelwood

Traditional biomass accounts for 92% of the Tanzanian energy supply and consists mainly of fuelwood and charcoal. However, in arid rural areas, also crop residues and cow dung are utilized in times of woodfuel scarcity at the end of the rain season (TAFORI 2005). Utilization of these fuels is rather location specific and it is not known to what extend they contribute to the overall traditional biomass consumption, though, its overall contribution is considered only a small fraction of the woodfuel consumption. Energy consumption in rural areas account for 85% of the total energy consumption (MEM 2003) and is almost completely made up of traditional biomass. Besides woodfuel, households collect wood for construction materials like poles, withies, ropes and crafts (Monela *et al.* 2005). Furthermore, woodfuel is consumed in village industries like tobacco curing, brick making, fish smoking, etc (Johnsen 1999). 9% Of all traditional biomass is consumed in the large-scale industry sector (IEA 2008). The average household woodfuel consumption in Tanzania has been analyzed frequently over the past decades, as shown in Table 1. However, the results vary significantly, from 0.73–1.50 tonne per capita annually, depending on the location of the survey and the season in which the survey was carried out. Furthermore, the average consumption has declined due to woodfuel scarcity and partly due to increased efficiency in woodfuel utilization (Kaale 2005).

Annual per capita woodfuel consumption (tonne/capita/year)	source
1.40	(Fleuret and Fleuret, 1978)*
0.80	(Openshaw, 1978)*
0.73	(Skutsch 1983)
1.70	(UN 1993)
0.85	(MNRT 1998)
0.87	(EC-FAO 1999)
1.09	(FAO 2005b)
0.75 – 1.13	(Kaale 2005)

Table 1: Overview of annual per capita woodfuel consumption in Tanzania, as determined by various authors. Volumes of wood were converted to weight assuming a wood density of 0.85 tonne dm/m^3 and charcoal consumption was converted to wood assuming a kiln efficiency of 19% on a dry-weight basis (Malimbwi *et al.* 2007). *In (Bradley 1991).

Like all household tasks, fuelwood collecting in Tanzania is a task generally performed by women. To give an idea of the impact of fuelwood as an energy source on rural livelihoods, especially on women: Taking an annual fuelwood consumption of 1 tonne/cap/year, an average rural household size of 5 persons and an average walking distance for fuelwood collecting of 3.15 km per day in rural areas (NBS 2001), it can be simply computed that on average, women have to collect and carry 13.7 kg of fuelwood each day, over a distance of 6.3 km, This is an average, meaning that there are areas were the burden of fuelwood collecting is much larger, foremost in dryer areas with a lower biomass cover. Fuelwood collecting is an activity which may take several hours per day (Johnsen 1999). It needs no emphasis that this burden puts a great constraint on the time women can spend on other tasks, like taking care of children or subsistence agriculture.

During the 70’s and early 80’s, it was thought that the daily quest for fuelwood was the main cause of deforestation and would eventually lead to depletion of forest resources. These studies were based on the overall disparity between de demand for fuelwood on the one hand and the natural growth increment on the other hand (Kaale *et al.* 1985), (See Figure 7). However, during the second half of the 80’s it became clear that these scenarios were strongly exaggerated (Johnsen 1999; Mwampamba 2007). The villagization of 1974-1976 had the effect of clearing vast areas for agriculture around the newly enlarged villages and vastly increasing the distances people had to walk to fetch fuel wood (Skutsch 1983). This released more remote areas from pressure of deforestation. Deforestation became more local, only around the villages. Furthermore, fuelwood gathering is normally done by collecting branches instead of cutting down a whole tree (Johnsen 1999). Per capita woodfuel consumption varies significantly per region, depending on the woody biomass density. In areas with a low woody biomass cover, the annual consumption is lower as the demand, resulting in a woodfuel deficit, or energy poverty, as shown in Figure 3:

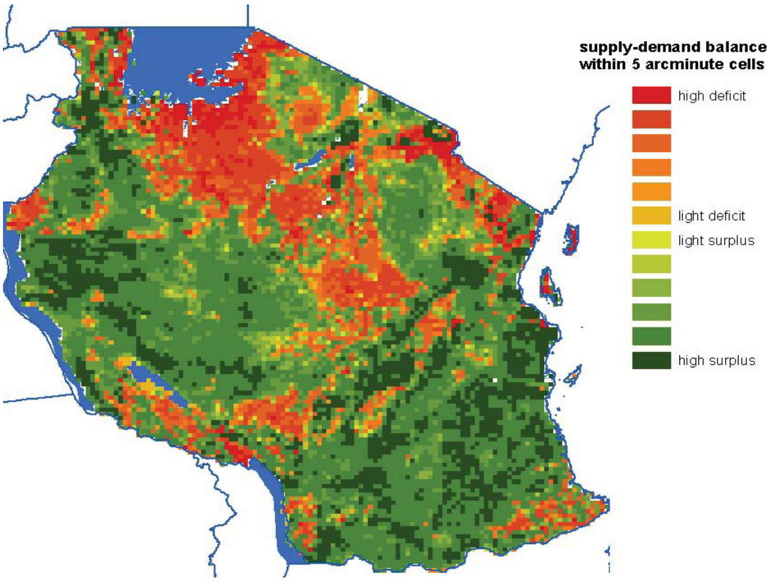

Figure 3: Fuelwood supply and demand balance in Tanzania, showing the areas with a fuelwood deficit in red. Source: (FAO 2005b).

Continuous deforestation leads to an increase of these woodfuel deficit areas and increases the time women have to spend on collecting fuelwood. The dependence on woodfuel for daily energy needs and low energy consumption because of energy poverty is seriously hindering rural economic development and overall poverty reduction efforts in Tanzania (Kaale 2005).

80.000 ha of plantation forest is established in Tanzania and 70.000 ha of forest is privately owned (MEM 2003). To combat deforestation, the government is promoting tree planting through several government acts. In 1999, a national campaign on tree planting was initiated and about 100 million trees were planted (Tanzania 2008). Furthermore, the 1st of January is designated as the National Day for Tree Planting, though this is more symbolical. Overall, planting figures tend to give a too positive view since at the end it matters how many trees are successfully raised instead of planted. Especially trees planted on public or communal village land have high mortality rates, since there is a lack of a sense of ownership. Therefore, woodlots should be based on private lands, though these lands are foremost needed for food production (Chamshama 2007). In order to produce fuelwood or charcoal, one needs to pay an annual government registration fee, which costs Tsh 200.000 (US$ 160) per year. Furthermore, there is a payable fee on each unit of fuelwood, charcoal, timber, etc. produced, on both national, district and village level. If one wishes to establish a woodlot for woodfuel production on private land, the annual government registration fee still applies and is independent of the woodlot size. However, the payable fee per unit of wood is reduced with 80% (Maganga 2007).

Quite contradictive to the heavy burden of collecting, fuelwood is mostly burned in simple 3-stone stoves with very low efficiencies, as shown in Table 2. In comparison, the fuelwood cooking efficiency in Tanzania is 2-3 times lower as in Asian rural areas (TAFORI 2005). Cooking efficiencies can be determined from experiments or by doing a field survey. The former tend to be too optimistic, while a field survey can give a more realistic picture of the real efficiency (Ishengoma 2007; Pesambili 2007).

Thermal efficiency	Source
5%	(Ishengoma 2007)
8 – 12%	(Pesambili 2007)
10 – 18%	(MNRT 2001)
7 – 12%	(Kaale 2005)
5%	(Carl Bro Int. 1983 in Johnsen, 1999)
10%	(Kaltschmitt, 2001 in Jürgens, 2006)

Table 2: Household fuelwood cooking efficiency in Tanzania.

Why would rural households not invest in improving their cooking efficiency and decrease the burden of fuelwood collecting? This is a question that still lacks a definitive answer, if possible (Ngaga 2007). One explanation is related to social differences in the perception of need for fuelwood: Wood is not regarded as an economic resource, because it can be harvested ‘free’ from public forests. Likewise, time spend by women is not regarded as an economic resource, since household tasks of women are regarded as ‘free’, as it is men who make most of the decisions and they might rate women’s labour low (Skutsch 1983; Ngaga 2007). In other words: Both fuelwood and time are not perceived as a *commodity*. Furthermore, it might be that women enjoy fuel gathering more than their other tasks, which can be quite enjoyable as it is often done in groups. They may not feel that the hours devoted to this should be shortened (Skutsch 1983). Additionally, many poor people have no cash for even relatively small investments and if they would have, they would not spend it easily on a cooking stove, since they would not earn their investment back directly since they do not avoid any direct costs (Johnsen 1999). Finally, there is simply a lack of knowledge in rural Tanzania of how to effectively improve rural household cooking efficiency (Kaale 2005). Different types and qualities of improved fuelwood cooking stoves are available; from relative inefficient (20%), constructed from clay and grass at zero costs, but having a short lifespan, to more efficient (30%), made from bricks or metal, having a long lifespan, but at a considerable investment cost. Philips recently developed a wood cooking stove for use in developing countries with a claimed efficiency of 70% (Philips 2008). However, this stove is relatively costly. Some types of improved stoves are portable. This is important since an advantage of the 3-stone stove is that it can be easily replaced (Pesambili 2007). Several programs on improved cooking efficiency have been undertaken by the Ministry of Energy and Minerals (MEM) and various NGO’s. However, according to the MEM, shortage of capacity to teach rural communities is hindering wide adoption of improved wood stoves in rural areas (MEM 2003).

Another serious disadvantage of using traditional biomass for household cooking is the negative health impact of the released smoke. It is estimated that worldwide 1.6 million people die every year from diseases caused by indoor air pollution (WHO 2006). Improved, better isolated cooking stoves can considerably reduce emissions from (indoor) household cooking, because of better combustion and the possibility of a chimney. More detailed information on improved cooking stoves is available in appendix A.

2.1.6.2 Charcoal

Charcoal is a woodfuel that is mainly produced in rural areas and consumed in urban areas. It has a higher energy density compared to wood and is therefore easier and more economical to transport and to store in cities. Furthermore, it produces less smoke, which is a significant benefit in urban areas. Charcoal is produced in kilns by pyrolysis; a process in which the chemical structure of the wood is broken down under high temperature and in the near absence of oxygen. A major problem is the low average conversion efficiency of 19% on a dry-weight basis in Tanzania (Malimbwi *et al.* 2007), which results in a kiln energy efficiency of only 33%. However, charcoal as a cooking fuel is more efficient compared to wood, due to its higher energy density. Conventional charcoal stoves have an efficiency of 15–18% (Malimbwi *et al.* 2007), which is considerably higher than a conventional 3-stone fuelwood stove. Nevertheless, when considering a fuelwood stove efficiency of 7% and an energy content of 18 MJ/kg and 32 MJ/kg for air-dry wood and charcoal respectively (Rosillo-Calle *et al.* 2007), one needs 26% more wood when cooking on charcoal as compared to directly cooking on fuelwood.

The most widely used method for charcoal production is the earth kiln. Two varieties exist, namely the earth pit kiln and the earth mound kiln. An earth pit kiln is constructed by first digging a small pit in the ground. Then the wood is placed in the pit and lit from the bottom, after which the pit is covered with green leaves or metal sheet and earth, to prevent complete burning. The earth mound kiln is an arranged pile of wood, which is lit and covered by earth to block the air flow. Efficiencies of these kilns are normally low, ranging from 10–20% on a dry-weight basis; however, they largely depend on the skills and time invested by the charcoal producer. A skilled charcoal producer who uses well-dried wood can reach efficiencies of up to 30% (Malimbwi 2007). Apart from earth kilns, charcoal can be produced in metal kilns with efficiencies of 20–25% and in brick kilns with efficiencies of 25–35%, but this requires considerable investment costs. The kiln efficiency, even as the quality of the charcoal, is strongly depending on the wood species used. Generally, slower growing species with a higher wood density are favoured. However, in some species water is locked up so that it cannot be released by heating the wood. This negatively impacts the efficiency and quality of the charcoal. Furthermore, the age of the wood and the moisture content are influencing the quality and efficiency (Malimbwi *et al.* 2007).

Figure 4: Illegally produced charcoal transport by bicycle.

Three groups of charcoal producers can be divided: Full time, seasonal and occasional producers. Full time producers live within the forest areas and produce charcoal throughout the year, shifting to new areas when sources become depleted. In most cases these are poor immigrants to the area, often without formal education. Seasonal producers practice agriculture as their main occupation and produce charcoal only in the dry season. Occasional producers make charcoal to meet specific cash needs during the year. Charcoal is transported to towns by commercial charcoal dealers in trucks or on an individual basis, by bicycle. The profit margins on charcoal production, transport and retailing are small since competition is high (Malimbwi *et al.* 2007).

The central government is trying to control the charcoal market by issuing allowances for charcoal production, transport and trade. Producers and transporters have to pay an annual government registration fee and there are extra taxes per bag of charcoal produced on the national, district and village level. However, the government has difficulties in controlling charcoal production and transport. As a result, most of the charcoal is produced and transported illegally. A survey in 2007 showed that 80% of the consumed charcoal in Dar es Salaam entered the city illegally (Malimbwi *et al.* 2007). In 2006 the central government issued a temporary ban on charcoal production to halt continuous deforestation around cities. As a result the prices increased sharply, from Tsh 15.000 to Tsh 25.000. This attracted more people to produce charcoal illegally. When the ban was lifted, the prices did not decrease (Malimbwi *et al.* 2007). Illegal charcoal is generally produced in a significant less efficient way because illegal charcoal producers are hurrying to avoid being caught, thereby even increasing the rate of deforestation (Liana 2007).

It has been argued that charcoal consumption is relatively inefficient so that much more wood is needed compared to fuelwood. As a result, rapid urbanization would lead to an even higher pressure on the forest resources (Mwampamba 2007). However, as shown above, the overall end-use energy efficiency is not much worse for charcoal use as it is for fuelwood. However, consumption is relatively higher in urban areas, mainly because in these areas higher income groups are living who consume more energy. Furthermore, the real difference in negative impact between fuelwood and charcoal is not efficiency-based but spatially: For charcoal production forests are clear cut on a relatively small area in the vicinity of towns, while fuelwood is collected over a larger area, almost without clear cutting (Johnsen 1999). Mwampamba estimates the contribution of charcoal production to be 30–60% of the total annual deforestation in Tanzania, however more detailed research on this issue is needed (Mwampamba 2007). After being clear cut, the tree species in the dry woodlands of Tanzania regenerate from root suckers and coppices, an essential characteristic in these ecosystems because of the regular occurrence of forest fires (Malimbwi 2007).

The 2.8 million inhabitants of the city of Dar es Salaam depend heavily on charcoal for their energy needs. 78% of the households use charcoal as their main energy source. Secondly, kerosene is used. However, due to increasing fuel prices, more people are shifting to charcoal, even though the central government removed the 20% VAT on kerosene in 2006. It is estimated that every day 28.759 bags, weighting 56 kg, are consumed in Dar es Salaam. This is 1.611 tonne per day. For a sustainable production of such an amount, 1.5 million hectares of forest are needed at an annual growth increment of 2.4 m^3/ha (Malimbwi *et al.* 2007). Because of the growing demand, combined with rapid deforestation around Dar es Salaam, the distance to charcoal sources has increased from 50 km in the 70’s to 200 km in the 90’s. Most of the charcoal within the proximity of 60 km from Dar es Salaam comes from cashew nut and mango trees. Although it is assumed that the trees used for charcoal are the less productive ones, the loss in income and food supply as a result of charcoal production is not known (Malimbwi *et al.* 2007).

Currently, two governmental pilot plantations for sustainable charcoal production in Tanzania exist. Both are close to Dar es Salaam and both aim to supply sustainable charcoal to the city (Malimbwi *et al.* 2007). The approach of the Ruvu Fuelwood Pilot Project (RFPP) is to provide smallholders some land in a heavily degraded forest close to Dar es Salaam. On this land rotational woodlots are established with the aim of producing commercial woodfuel for Dar es Salaam. More information on this project can be found in appendix B. The central government is trying to improve the situation both on the supply side as on the demand side. On the demand side improved charcoal stoves and improved kilns are promoted to increase the efficiency of charcoal use. On the supply side sustainable charcoal production is promoted. However, smallholders wishing to start a woodlot for charcoal production, still have to pay the annual registration fee, as indicated above.

2.1.6.3 Modern energy sources

Tanzania has considerable coal reserves, but these are hardly used for electricity production, even though the Tanzanian government is promoting private investors to start utilizing these reserves by building a coal power plant. Furthermore, there are natural gas reserves, which are used for electricity generation. Tanzania has no oil reserves and thus has to import all its petroleum, which accounts for about 30% of the total foreign expenditures (TAFORI 2005). 75% of the imported petroleum products are used in the transport sector and 13% is used by households (IEA 2008). Tanzania's demand for petroleum products is growing rapidly at a rate of more than 30% per year (GTZ 2005).

The Tanzanian government acknowledges the potential of biofuels to replace the heavy financial burden of oil import. However, transport biofuels have only recently entered the debate. In 2006, the Ministry of Energy and Minerals assigned a Taskforce on Biofuels and a national biofuels policy strategy is under preparation (WIP 2006). So far there is no commercial biofuel production in Tanzania yet, although, Tanzania has a large potential. This is mostly due to inadequate technical know-how and the lack of policy support for biofuel development (GTZ 2005). The most promising oilseed crops for biofuel production are palm oil and Jatropha (WIP 2006). Nowadays, the first Jatropha plantations in Tanzania are established by international biofuel corporations. Furthermore, various initiatives are undertaken to promote Jatropha cultivation by smallholders. The Dar es Salaam-based development organisation TaTEDO is promoting so-called Multi-Functional Platforms (MFP). MFP's consist of a unit of machinery that can be utilized for different purposes, like electricity production and milling. The machinery is powered by a diesel engine and the aim of TaTEDO is to eventually fire this engine by locally produced Jatropha oil (TaTEDO 2008). However, the largest smallholder-based initiative is coming from Diligent, a Dutch commercial biofuel company based in Arusha, in the north of Tanzania. Diligent is promoting smallholders throughout the country to grow Jatropha seeds and is offering farmers a contract in which the purchase of Jatropha seeds is guaranteed for a period of 10 years and for a fixed price. This price is depending on the distance to the Diligent factory in Arusha. Smallholders can sell seeds to special pick-up points, spread out over the country. Most seeds are obtained from Jatropha hedges and little is yet produced by dedicated smallholder plantations (van Eijck 2007b). Jatropha soap production is practised widely across the world and is nowadays promoted by some NGO's in Tanzania (Manyanga 2007; Matchmaker 2007). Soap production has a great potential of generating income for women, which is an important additional benefit in rural Tanzania (Henning 2003). As a result, several women groups started Jatropha soap production, however a real market for Jatropha soap is still lacking.

2.1.6.4 Rural electrification

Electricity accounts for only 1.2% of the Total Final Consumption (TFC) in Tanzania (IEA 2008). The Tanzania Electric Supply Company (TANESCO) is a parastatal company that is responsible for the supply of electricity in Tanzania. Until recently, the electricity supply was almost completely covered by hydropower; however, poor rainfall in recent years has led to a dramatic decrease in production. In 2005 only 59% of the total electricity production was covered by hydropower. This resulted in power shortages which seriously harmed the economy. At the same time, electricity demand is increasing with 8% annually. Nowadays, TANESCO operates an installed capacity of 561 MW of hydropower plants. Additionally, the private company SONGAS is operating a 182 MW gas-fired power plant and IPTL and Aggreko are operating respectively 100 MW and 40 MW of diesel-fired power plants. To cover the increasing demand and reduce power shortages, TANESCO is building extra gas and diesel fired power plants; however, this strongly increases the cost of production compared to hydropower (TANESCO 2008), especially now the oil prices are skyrocketing.

Access to electricity in Tanzania is one the lowest in the world: In 2001, only 10% of the population had access to electricity and it is estimated that in 2001 only 2% of rural households had access to electricity (NBS 2001). In the 2003 Energy Policy, the Ministry of Energy and Minerals states that "Electricity needs to be made available for economic activities in rural areas, rural townships and commercial centres. Rural electrification is, therefore, a case of long-term national interest and a prerequisite for a balanced socio-economic growth for all Tanzania." Furthermore, the aim is to "Promote the application of alternative energy sources other than fuelwood and charcoal, in order to reduce deforestation, indoor health hazards and time spent by rural women in search of firewood." Rural electrification in Tanzania has been on-going since independence in 1963. So far, some 15 townships and 40 villages have been electrified by TANESCO, totalling 33.8 MW of diesel-fired capacity (Ilskog *et al.* 2005; TANESCO 2008). To increase accessibility to electricity for poorer households, TANESCO offers a special low usage domestic tariff of maximally 50 kWh per month. This subsidized tariff is financed by higher usage tariffs (TANESCO 2008). However, the subsidized low usage tariff of TANESCO acts as an obstacle for rural electrification. Low usage consumers dominate electricity use in rural towns and villages and therefore rural electrification is a heavy financial burden for TANESCO. The low electric load density and use of relatively expensive generation technology in isolated grids leads to comparatively high costs for electricity supply. In 2002, an isolated diesel-fired grid, run by a private co-operative in Urambo village, Tabora region, delivered electricity for US$$_{2007}$ 0,54 per kWh (Ilskog *et al.* 2005), compared to US$$_{2007}$ 0,04 per kWh, that is charged for national-grid-connected households in the low usage tariff.

Electrification does bring more than only the social improvement of lighting to rural areas. It can function as a catalyst for rural economies, both by extending the time that people can be productive and by offering the possibility of using electric equipment and start up small enterprises (Maleko 2005). Furthermore, modern media like radio and television become available. And last but not least, people can get access to a mobile telephone network, in case of network accessibility. The latter sounds a bit awkward for rural areas in a developing country, but the reality is that mobile connectivity is rapidly expanding in Tanzania and so is mobile phone use, even in rural areas. In order to foster rural development, the Tanzanian Government initiated the Rural Energy Agency (REA) and the Rural Energy Fund (REF) in 2005, with the purpose of "Facilitating the provision of modern energy services in rural areas" (MEM 2005). This agency has as its main task to promote investment from private investors in the Tanzanian rural energy sector. This is in line with the overall energy policy of the Tanzanian government, which is focused on market-oriented energy supply (MEM 2003). There is no government incentive on rural electrification using solar PV technology. Various NGO's are working on small projects throughout Tanzania, but the overall impact is not significant.

2.2 Shinyanga

This cost/benefit analysis is based on semi-arid East Shinyanga as a case study. In the following section, the characteristics of this region and the specific problems related to energy will be addressed.

2.2.1 Geography and climate

Shinyanga region is ecologically divided in a semi-arid eastern part, with an annual rainfall of 600 mm (Sinyanga Rural, Shinyanga Urban, Kishapu, Maswa, Meatu and Bariadi districts) and a sub-humid western part, with an annual rainfall of 1.200 mm (Bukombe and Kahama districts). Rainfall is unimodal and falls only from November to April, however variations in rainfall pattern and quantity are large. Shinyanga lies on the central highland plateau with altitudes varying from 1.000–1.500 m (Monela *et al.* 2005). The landscape is mostly flat, covered with isolated stone hills and dotted with giant baobab trees. The North-Eastern corner is part of the famous Serengeti national park. Historically, the natural forest cover of Shinyanga consisted of Miombo woodlands towards the west and acacia savannah towards the east. Bukombe district is still largely covered with Miombo and Acacia woodlands. However, from the 1920's, the colonial power massively cleared woodlands in Shinyanga for the eradication of tsetse flies. This fly transmitted a livestock disease and its eradication led to a sharp increase in livestock numbers. Forests were also cleared for agricultural expansion, foremost the production of cotton and tobacco. This massive deforestation led to severe land degradation. A major effect of this land degradation is water shortage. Trees and grasses that once stopped the rain from striking bare soil have vanished, leaving the rain to rush away in torrents, causing soil erosion, desiccation and further land degradation. By the 1980's, large areas in Shinyanga were complete denuded of vegetation and seemed beyond recovery (Mlenge 2004).

Figure 5: The eight districts of Shinyanga region, divided in a semi-arid eastern and a sub-humid western part.

Figure 6: Characteristic landscape in East Shinyanga during the end of the dry season.

2.2.2 Socio-economics

Population pressure is the main driver for the increased pressure on the natural resources of Shinyanga. In 2006, Shinyanga region had an estimated population of 3.2 million people and 6.3 people per household, at a growth rate of 3.3% (OXFAM 2007). Only 6% of the population lives in urban areas (NBS 2001), the main municipality being Shinyanga town. The semi-arid areas in Tanzania are characterized by huge livestock populations and Shinyanga is no exception. Shinyanga is traditionally home to the Sukuma tribe, who are agro-pastoralists and make up 80% of the population. The Sukuma strongly maintain their tradition. Their livestock, especially cattle, is playing a central role in meeting social and economic needs. Apart from producing milk, meat and draught power, the number of livestock owned is a measure of one's wealth and status in the Sukuma community and is used to pay bride prices (Mlenge 2004). In many semi-arid areas, cattle are valued more than anything else and are used as a safety net or insurance, since agricultural yields are rather insecure in dry areas. In case of crop failure or sudden need for cash, one can always fall back on cattle, by butchering or selling a cow (Barrow 1996). However, this is traditionally seen as a last resort, as professor Monela pointed out: "One can own a thousand cows, but no tooth brush" (Monela 2007). People prefer having cattle than money on a bank account. Livestock wealth is thus a central component in people's livelihoods. It is playing an elementary role in everyday live in Shinyanga and as a result, it has to be incorporated in any land use plan (Rubanza 2007). Shinyanga has by far the largest livestock population in Tanzania, with 2.6 million cows, 1.3 million goats and 5.2 million sheep (Shinyanga 2005). The grazing pressure of this livestock on the land is enormous and as a result, land degradation because of overgrazing is severe. The official grazing capacity in Shinyanga is 2 ha/livestock unit, however, nowadays 4–12 ha/livestock unit is a better estimation (Mahuyemba 2007). The regional government is trying to decrease the livestock pressure by up-scaling the meat industry and promoting higher quality cattle and thus, quality above quantity. Though, as indicated above, these efforts are constraint by cultural boundaries (Mahuyemba 2007).

As in the rest of Tanzania, agriculture is the main economic activity in Shinyanga. Over 46% of the land surface is considered to be arable land (OXFAM 2007). Maize and sorghum are the main staple crops, while cotton and tobacco are the main cash crops (Monela *et al.* 2005). The yields in Shinyanga are below the Tanzanian average, with an average maize yield of 0.92 tonne/ha in Shinyanga over the period 1996–2003, compared to 1.33 tonne/ha in the whole of Tanzania (MAFC 2008). The yields are lower in Shinyanga because of the inherent low soil fertility, low fertilizer inputs, poor rainfall and poor traditional crop management (HASHI 1998). Farmers in Shinyanga plant different types of crops to spread the risk of failure, so they have a number of crops to deal with. They face an enormous pressure during the sowing time at the beginning of the wet season and the harvesting time at the end, since they have to plant and harvest all their crops in a very limited time (Mashaka 2007). As a result, management is most of the time not optimal, a problem that is increased by the unpredictable rainfall patterns. Furthermore, after subsequent years of cropping, yield decreases because of nutrient depletion and land has to be left fallow for some years, however, often overgrazing is preventing land from regenerating sufficiently (Ramadhani *et al.* 2001; Monela *et al.* 2005). Low agricultural yields result in a low return on labour, which obstructs the possibility to invest in better seeds or fertilizers for the next season and hampers smallholders from escaping poverty. Despite its abundance in Shinyanga, cow dung is hardly used as a fertilizer. This is mainly because of cultural reasons and the fact that it is hard to collect manure from free roaming cattle (HASHI 1998; Mashaka 2007). Crop production in Sukumaland used to be characterized by shifting cultivation and long fallow periods to increase soil fertility. However, due to increasing population pressure, this has changed to almost permanent cultivation with short fallow periods (HASHI 1998). The average farm size is 3.2 ha of cultivated land. This is often too much for a farmer to attend properly; e.g. ideally, cereals should be planted in rows, but many farmers plant randomly, so they have problems with harvesting. Therefore, the regional government is emphasizing the focus on using less land, but with better management to increase productivity. Thus, in general smallholders are more constrained by their labour capacity as by their land capacity. Weeding is often carried out insufficiently because of a lack of labour capacity. Farmers with some cash can hire special weeding teams and weeding is the most applied labour attracted (Mashaka 2007). Many poor smallholders own only 1–2 acres of agricultural land for subsistence cropping. This is too little, so they work as land workers. These land workers are often the poorest in society. Often, they get paid in food or services, or they may use land for own production in return for work (Mapundo *et al.* 2007). They have no productive assets to invest, which prevents them from escaping from poverty. However, since recently, the regional government started promoting micro credit as a means to enhance investment availability amongst farmers, including women (OXFAM 2007).

Related to this, limited market access due to the absence of a market structure in remote rural areas is another problem that hampers rural economic development. Staple crops are foremost grown for subsistence purposes and what is left is sold at local isolated village markets. Besides the fact that larger markets are often far away, resulting in high transportation costs, there is also limited access to market information in rural areas. Farmers often do not have knowledge of regional market prices and market opportunities, resulting in inadequate negotiation power towards transporters. Added to this, the seasonality of agricultural supply leads to an extreme drop of prices during the harvesting season. As a result, poverty rates are higher in more remote areas (OXFAM 2007).

On average, there is a relatively large amount land available to smallholders in Shinyanga. The average land ownership is 5.8 ha per household, which almost three times higher as the Tanzanian average (NBS 2001). However, the disparity between different wealth groups is large, as shown in Table 3, which shows an estimation made by various officers of the Shinyanga Rural district government (Mapundo et al. 2007). Basically, people in the Sukuma society differentiate between three wealth groups: *Nsabi*, *Hambo hambo* and *Nghabi*:

Wealth group	Percentage (%)	Land ownership (ha)	Livestock (heads)	Type of house	Food supply
Rich *Nsabi*	10	> 40	> 50	Big house, cement or brick walls.	Surplus
Medium *Hambo hambo*	70	2.5 - 40	11 – 49	More than 2 rooms and veranda.	Subsistence to surplus
Poor *Nghabi*	20	< 2.5	< 10	Small house, traditional mud and grass roof.	Subsistence to deficit

Table 3: Estimation of wealth groups in Shinyanga rural. Estimated on 8-11-2007 by: K. Mapundo, District Agriculture & Livestock Development Officer, J.T. Mulongo, Livestock Officer, B.A. Moshi, Subject Matter Specialist Crops, S.P.N. Sanyiwa, Subject Matter Specialist Livestock Production, I. Modaha, Subject Matter Specialist Agromechanization, District Government of Shinyanga rural.

A relatively small group owns large tracts of land, while the poorest only have access to a few acres. However, most people are *hambo hambo*. For medium and high income groups, not all land is used for cultivation. This land can serve various functions, but is mostly used for cattle grazing, since land ownership and livestock ownership are strongly correlated (Mapundo *et al.* 2007). Livestock is estimated in heads, which can be cows, goats or sheep. In case of *Nghabi*, livestock is only sheep and goats, while *Nsabi* foremost own cattle. Crop residues left on the field are grazed by cattle after the growing season. Land tenure is foremost customary in rural Shinyanga. Despite the huge resource base, land is fragmenting, because of the rapidly increasing population. Communal village land is disappearing, since it is more and more privately owned (Mlenge 2007). General land that is feasible for cultivation is being claimed for agriculture and only marginal land is left for grazing (Monela 2007). This general land might not be owned, but it still falls under customary law. This system is needed to avoid overexploitation of these lands, since grasslands are a very valuable commodity in the Sukuma culture. Renting land is common in Shinyanga, especially grazing land. Furthermore, poor smallholders are often forced to rent extra land for cultivation. Regularly, this is paid for in natural payments, like milk or labour (Msuya *et al.* 2006; Mlenge 2007).

Shinyanga is one of Tanzania's poorest regions. The 2000/01 Household Budget Survey of the National Bureau of Statistics presented an average income of US$$_{2007}$ 186 and US$$_{2007}$ 400[*] for rural and urban households in Shinyanga, respectively. Furthermore, 71% of the rural income was obtained from agriculture and 3% from livestock (NBS 2001). The share of livestock looks relatively low, considering the numbers of livestock present in Shinyanga. However, as indicated before, livestock is more a cultural than an economical commodity and furthermore, these statistics can be seriously flawed since they only take into account financial income and trade at official markets. It is rather difficult to measure income and trade in rural Shinyanga, because of the reciprocal nature of the local economy and the large share of subsistence activities. Therefore, livestock ownership is a better indication of welfare as cash income (Mahuyemba 2007; Mapundo *et al.* 2007).

Several livelihood surveys have recently been undertaken in Shinyanga (Shinyanga 1998; Morris *et al.* 2002; EDI 2004; Monela *et al.* 2005; OXFAM 2007). It was found that 30% of the population still lives under the Basic Needs Poverty Line and in rural areas this poverty rate is 42%. Food shortages are happening primarily in the wet season when extensive labour is needed for land cultivation. Education levels are relatively low in Shinyanga. 41% of the population is illiterate and there are big differences across gender. On the other hand, nowadays primary school enrolment is high, so that illiteracy is decreasing rapidly. Access to drinking water is a major problem in semi-arid Shinyanga. Drinking water sources are often far away and collecting water can be a heavy burden for women. 33% of all households in rural Shinyanga live more than 30 minutes walking distance from the nearest water source (EDI 2004).

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[*] Income corrected using a Consumer Price Index (CPI) for Tanzania (USDA 2007) and converted to US$ using the average 2007 exchange rate: 1 US$ is 1205 Tsh. Source: Oanda 2008.

2.2.3 Energy supply and demand

In 1985, an alarming rapport was written about the state of deforestation and fuelwood supply in Shinyanga. It was projected that the unsustainable use of the remaining forests, in combination with rapid population growth, would eventually lead to total depletion of forests resources in Shinyanga, as illustrated in Figure 7. Immediate tree planting was emphasized as way to avoid further forest degradation.

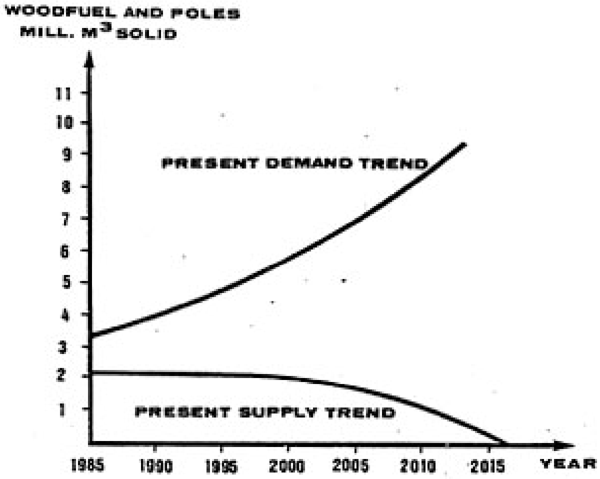

Figure 7: Wood demand and supply projections in Shinyanga in 1985 (Kaale et al. 1985).

Furthermore, it was estimated that the woodfuel deficit was severe in the rural areas of East-Shinyanga, where 32% of the energy consumption was originating from agricultural residues and cow dung (Kaale *et al.* 1985). However, as indicated before, these demand/supply projections turned out to be too pessimistic.

Since then, a lot has changed in Shinyanga. In 1986 a programme under the ministry of Natural Resources and Tourism was started, with the focus on encouraging the village governments of Shinyanga to reverse the natural resources destruction by using their own traditional knowledge to reclaim the land. The programme was called *Hifadhi Ardhi Shinyanga* (HASHI), which means 'soil conservation' in Swahili. Through training and demonstrations the Sukuma began to reintroduce their indigenous natural resource management system, called *Ngitili*, to restore the woodland ecosystems after years of deforestation and overgrazing (Mlenge 2004). *Ngitili* is grazing land which is left fallow so that the natural vegetation can regenerate. It is opened for grazing only at the end of the dry season, when other grazing land is exhausted. After grazing, fuelwood can be obtained from the regenerated trees on the *Ngitili* land. The focus is thus on regeneration of woodlands, instead of planting new trees, which proved to be rather unsuccessful, especially in dry areas. The main reasons for the lack of success of tree planting in Shinyanga are high mortality rates, a lack of responsibility, forest fires and damage caused by cattle (Mbwambo 2004; Chamshama 2007).

The HASHI program turned out to be a remarkable success and nowadays Ngitili are scattered throughout the Shinyanga landscape. The remaining communal lands are all Ngitili. Ngitili are managed by customary law and protected by *Sungu Sungu*, a powerful traditional security group. Besides being a source of vegetation fodder, Ngitili can provide leguminous fodder, fuelwood, construction materials, mushrooms, gum, medicinal plants and fruits for a local community. Furthermore, Ngitili can be used for bee-keeping activities. Monela *et al.* valuated the total economic benefits of people having access to well-managed Ngitili to be US$ 168 per person per year (Monela *et al.* 2005). This valuation implicitly showed how economically dependent these people are on their natural resource base. From 1991 HASHI is cooperating with the World Agroforestry Centre (ICRAF) on the development of appropriate agroforestry technologies for farmers, with the purpose to improve fuelwood and fodder production and to improve soil fertility in Shinyanga. Besides Ngitili, the focus is on rotational woodlots, fodder banks, improved fallows and boundary planting (HASHI 1998).

Agroforestry in Shinyanga consists of crops, trees and livestock and is an intervention to maximize the production of an area of land (Bakengesa 2007). Major constraints for farmers to practise agroforestry on private land are lack of knowledge, lack of available seedlings and the long period before return on investment is realized (HASHI 1997). This problem is enhanced by insecure land tenure. Many poor farmers do not own all the land they use for cultivation of crops, so that planting trees is regarded as too risky since they might loose the land (Msuya et al. 2006). Furthermore, many farmers are rather conservative and do not invest in agroforestry even though they have the resources and observe the benefits for farmers who adopted agroforestry (Bakengesa 2007). At last, as indicated before, in Tanzania a license is needed for commercial woodfuel production and taxes are levied on each unit of commercial woodfuel. However, it is not clear to what extend these government regulations are enforced in practise, since most of the charcoal produced and traded in Shinyanga town is illegal. Despite all these constraints, nowadays agroforestry technologies are adopted widely in Shinyanga, but only by *Hambo hambo* or *Nghabi*, farmers who have enough land and resources to invest (HASHI 1997; Bakengesa 2007). Some farmers even refuse to cut down the trees after several years of growing because they became too attached to them (Minja 2007).

Besides all these efforts, the regional government of Shinyanga is still promoting tree planting through national tree planting directives. It has launched a tree planting program which commits each district to plant 1.5 million trees on average per year. Furthermore, a directive issued by the regional government in 2006 commits each person to plant one tree per year. The regional government has started several nurseries close to water sources and is distributing tree seedlings free of charge to initiate people to plant trees (Maganga 2007).

Despite all these efforts, East Shinyanga is still facing a fuelwood deficit (see Figure 3). Fuelwood scarcity has led to fuelwood commercialisation (HASHI 1998), which predominantly affects poor people. People owning ox-carts are able to collect larger quantities of fuelwood and sell these per headload at local markets (Shinyanga 1998). As a result of wood scarcity, crop residues and cow dung are still relied upon as an energy source in times of fuelwood depletion and fuelwood consumption is considerably lower as the Tanzanian average. Fuelwood is picked during the last three to four months of the dry season and is stacked for use during the wet season. People first dry the collected wood in order to increase the burning quality. Households in rural Shinyanga spend around eight hours per day on fuelwood collecting during the fuelwood pick months; however this varies strongly per location. Despite the fuelwood scarcity, most people use 3-stone stoves (Bakengesa 2007). A survey performed in 1997 indicated that lack of knowledge of how to construct a mud stove and the short life span of mud stoves was the main reason for limited utilization of better isolated cooking stoves (HASHI 1998), (See appendix A).

In Shinyanga town, charcoal is the most utilized energy source. Charcoal is sold in two qualities: locally produced, lower quality acacia charcoal and higher quality Miombo charcoal, produced in West Shinyanga and Tabora region. Like in Dar es Salaam, the majority of the charcoal is produced illegally. Because of the limited supply and commercialisation of fuelwood, charcoal is not only used in urban areas, but also preferred in villages in the vicinity of urban areas, since it is a much more comfortable energy source for cooking, compared to fuelwood, mainly because less attention is needed. However, only better-off households can afford charcoal.

Diesel and kerosene are relatively expensive in Shinyanga. Since Tanzania is a large country with a relatively less developed infrastructure, transport fuel prices rapidly increase in more isolated rural areas, as can be seen in Table 4. In October 2007, a price of US$ 1,49 per litre diesel was found in Shinyanga Rural district, which is unaffordable for the majority of the population. However, on every litre of transport fuel, Tsh 200 (US$ 0,17) of government levy and Tsh 100 (US$ 0,083) of road toll is charged (TRA 2008).

Location	**Distance to Dar es Salaam (km)**	**Diesel price in Tsh/litre (US$/litre)**	**Kerosene price in Tsh/litre (US$/litre)**
Dar es Salaam	-	1.380 (1,15)	1.000 (0,83)
Morogoro	190	1.380 (1,15)	1.000 (0,83)
Arusha	629	1.525 (1,27)	1.050 (0,87)
Shinyanga urban	971	1.525 (1,27)	1.100 (0,91)
Shinyanga rural	>971	1.800 (1,49)	1.500 (1,25)

Table 4: Consumer fuel prices in Tanzania relative to the distance from the capital Dar es Salaam, in October 2007.

There is practically no rural electrification in Shinyanga and kerosene is the most widely used form of lighting (NBS 2001). The rapidly increasing kerosene price is an increasing burden on many rural households.

3. Sustainable biomass energy supply systems

From the previous chapter, it can be concluded that the energy situation in rural Shinyanga is far from positive. Furthermore, there is a large gap between traditional biomass energy and modern energy sources. This research aims to contribute to filling this gap by exploring the economic feasibility of alternative and sustainable biomass energy supply systems. As indicated in the introduction, I selected three different systems that might have potential for this purpose: Carbon forestry, rotational woodlots and Jatropha oil production. In this chapter, the general principles of these systems are further explained and analyzed. In the next chapter, the methodology of each of these systems is presented.

3.1 Carbon forestry

3.1.1 The Clean Development Mechanism

Human land use activities change natural carbon stocks and flows. The International Panel on Climate Change (IPCC) has collected these activities under the somewhat extensive acronym *Land Use, Land Use Change and Forestry* (LULUCF). Substantial amounts of carbon have been released from forest clearing over the last several centuries, especially from the tropics during the latter part of the 20th century (IPCC 2000). Presently, around 23% of all CO_2 emissions emanate from worldwide deforestation and devegetation (Dutschke 2007). Under the Kyoto Protocol, Parties to the Convention approved the inclusion of LULUCF activities as a way to mitigate global warming and foster sustainable rural development of developing countries. Presently, of all LULUCF activities, only afforestation and reforestation activities are included in the Clean Development Mechanism (CDM) under the Kyoto Protocol. Proper methodologies for other land use activities could not be agreed upon, however the debate is ongoing.

The Clean Development Mechanism (CDM) is a Kyoto Mechanism that allows Annex I Parties to implement sustainable development projects that reduce CO_2 emissions in non-Annex I Parties. Project approval under the CDM is based on two main criteria. The first is so-called *additionality*. This means that the project must lead to proven greenhouse gas emission reductions that would not have occurred in the absence of the project. As a consequence, the extra benefits gained by the trade in Certified Emission Reductions (CERs) must directly lead to the economical viability of the project. The second criterion is that the project must facilitate *sustainable development* of the local population, to avoid exploitation of humans and resources in developing countries for the purpose of mitigating greenhouse gasses (UNFCCC 2005). *Permanence* concerns the durability and stability of a carbon stock in a land use system. The stock might be permanent in theory, but is in practice potentially reversible through human activities and environmental change, including fires (Roshetko *et al.* 2005). To tackle the permanence problem and because of concerns related to land use sovereignty of developing countries, the concept of tCERs and lCERs was adopted in 2003. A tCER, or temporary CER, is a CER which expires at the end of the 5-year commitment period following the one during which it was issued. An lCER, or long-term CER, expires at the end of the crediting period of the forestation project for which it was issued. Thus, forestation projects can never lead to permanent sequestration, since the tCERs and lCERs have to be replaced later on. This seriously affects the attractiveness of forestation projects compared to permanent mitigation (UNFCCC 2004).

The first forestation CDM project was only approved in November 2006, in China. However, there are a number of forestation projects in the pipeline for approval (UNFCCC 2008). The costs related to validation, monitoring and verification of

CDM projects can be substantial. In order to decrease these CDM transaction costs for smaller size projects, the CDM Executive Board (EB) is developing 'lighter' approval methodologies. Small-scale projects may not generate more than 8 ktonne CO_2 equivalent per annum on an average of five years and are specifically aimed at low-income communities. Afforestation and reforestation is included in these small-scale methodologies (UNFCCC 2004). Transaction costs are both lowered by the simplified procedure itself and by the fact that the CDM Executive Board does not impose registration costs on small-scale projects (UNFCCC 2006). The economic feasibility of small-scale forestation projects have been studied by Cacho *et al.* and Locatelli *et al*. Both indicate that the transaction costs are still too high to make small-scale projects economically feasible (Locatelli *et al.* 2006; Cacho *et al.* 2007). Momentarily, the Subsidiary Body for Scientific and Technological Advice is studying the possibility to raise the cap of 8 ktonne CO_2 per year, in order to increase the economic feasibility of small-scale forestation projects (UNFCCC 2007c).

The fact that there is currently only one forestation project approved under the CDM does not mean that there is no carbon credit market for these projects yet. Forestation projects found wide application in the Activities Implemented Jointly (AIJ) pilot phase of the UNFCCC (Van Vliet *et al.* 2003). Furthermore, in 2000, the World Bank launched its Prototype Carbon Fund, which intended to include forestry projects. In the following years, the World Bank had launched two additional carbon funds that include LULUCF activities: the BioCarbon Fund (BCF) and the Community Development Carbon Fund (CDCF). The CDCF focuses specifically on buying carbon credits from projects working with rural communities in developing countries. Basically, these funds are designed as Kyoto pre-compliance mechanisms (Jürgens *et al.* 2006).

Tanzania ratified the Kyoto protocol and is thus one of the non-Annex I parties that can act as a host country for CDM projects. The Tanzanian government is recognizing the potential of the CDM and is actively promoting the implementation of CDM projects (EPMS 2004). However, momentarily there is only one project in Dar es Salaam validated by the CDM Executive Board. This project is based on recovering methane from a landfill, one of the most popular CDM project activities. Furthermore, there is one large-scale afforestation project in Tanzania in the pipeline for validation by the CDM Executive Board (UNEP-RISOE 2008). This project is situated on former grasslands in the south of Tanzania and aims to establish a large-scale, sustainable managed forest plantation. Tanzania is the host country but is not a project participant. The project developer has received a title deed for the period of 99 years from the Tanzanian government. This includes compensation for local communities living in the area under the Village Land Act. The project is developed by a Norwegian forest company that established a subsidiary in Tanzania, which is the official project participant. The carbon credits will be bought by the Norwegian government. To fulfil the demands for sustainable local development, 10% of the carbon benefits will be used for local development projects (UNFCCC 2007a).

3.1.2 The voluntary carbon market

Parallel to the CDM, a voluntary market for carbon offsets has emerged. This voluntary market consists of companies, governments, organizations and individuals that voluntarily purchase carbon offsets to 'compensate' their greenhouse gas emissions. These voluntary offsets can be bought from retailers that invest in a wide range of offset projects, like forestation or renewable energy. As these retailers sell to the voluntary market, the projects in which they invest do not necessarily have to follow the CDM project cycle. Free of the stringent guidelines, lengthy paper work, and high transaction costs, project developers have more freedom to invest in small-scale community based projects

(Taiyab 2006). At the one hand, sellers on this market aim to lower the cost of carbon credits. On the other hand, buyers demand integrity of the carbon credits they buy. This trade-off has resulted in a wide variety of standards for these projects. Voluntary forestation carbon projects are thus not a homogenous group, since there is no international standard yet. However, such a standard, the *Voluntary Carbon Standard*, is in progress (VCS 2008). Many voluntary afforestation projects follow general CDM guidelines and consult a third party, a so-called Designated Operational Entity (DOE) in CDM-terms, for project validation, verification and certification. However, the bureaucratic procedures associated with the CDM registration process can be avoided (Taiyab 2006). In contrast to the CDM, the voluntary market is momentarily largely based on forestation projects. This is mainly because of low investment cost and marketing purposes: Forestry projects generally result in relatively low carbon mitigation costs and forestation carbon credits on the voluntary market are permanent. Furthermore, forestation resembles to nature conservation, which is more appealing to the public (Snoep 2007). At the moment, the voluntary carbon market is just a fraction of the size of the Kyoto-based carbon market, but is rapidly growing (Harris 2006).

The opportunity of trading forestry carbon credits on the Kyoto-based market or the voluntary market may provide a significant forestation incentive to developing countries. As indicated in the previous chapter, the national government and the local government of Shinyanga have undertaken several initiatives towards forest planting in Shinyanga, but this was unsuccessful, mainly because of high mortality rates, lack of responsibility, lack of funds, forest fires and cattle grazing. The benefits of carbon trade could remove these barriers. On the other hand, in Shinyanga, a strategy based on regeneration of woodlands, instead of planting new trees, proved to be more successful. However, forest regeneration is not (yet) eligible for carbon sequestration under the CDM.

3.1.3 Biomass energy from carbon forestry

The small-scale forestation methodology was originally designed to make the CDM benefits available to rural smallholders, who would otherwise be excluded from this mechanism. For example, a project developer can stimulate smallholders to practise agroforestry on their land and obtain extra income from the environmental service of carbon storage. While each smallholder plot will be of limited size, the combined effort of large groups of smallholders can store a significant amount of CO_2 (Roshetko *et al.* 2005; Cacho *et al.* 2007). Several of such initiatives are momentarily running in Sub-Saharan Africa. Good examples are the *Nhambita* project in Mozambique (www.planvivo.org), or the TIST projects in Kenya and Tanzania (www.tist.org), though these projects are aimed at the voluntary market. However, to create income from carbon forestry, trees should be left untouched, while for fuelwood production, wood should be harvested. These two seem to contradict, so the next question is: How could a small-scale carbon forestry project be a source of fuelwood for local smallholders in East Shinyanga?

The advantage of smallholder participation is the fact that farmers directly own the productive asset, which they can use for their own benefits, e.g. fruit trees and carbon income. However, this does not stimulate sustainable fuelwood production. Assume a smallholder who practises tree growing and aims to maximize his/her profits. He would not harvest any wood if the benefits of carbon income are higher as the opportunity of harvesting and selling fuelwood or timber. Vice versa, he would cut the trees after a few years if the income from fuelwood or timber would be larger as the income from carbon storage. The latter is most likely to be the case, since in East Shinyanga, were fuelwood scarcity has led to commercialisation and the cost of wood is relatively high, it is not likely that the income from carbon credits per tonne of wood is higher as the opportunity of selling the wood. In this line of reasoning, there is no logical reason for a farmer to reserve a few trees for fuelwood needs while keeping the rest for carbon mitigation. Furthermore, growing trees on smallholder agricultural land for the purpose of carbon storage can compete with food production since the trees are growing for multiple decades. This is not preferable, especially since there are large tracts of general lands in Shinyanga that can be used for carbon forestry (Rubanza 2007). A project similar to the Ruvu Fuelwood Pilot Project (see appendix B) could be designed in which smallholders are assigned patches of general land, which they can use to grow trees for carbon payments. However, this is likely to result in higher forest management costs per hectare, compared to a more central executed forestation project were economies of scale apply. Furthermore, the first experiences of the Ruvu project were disappointing since most farmers have cut their trees earlier as planned to sell them as poles (Liana 2007).

Therefore, a centrally organized carbon forest on general land, in which a local community participates, might be a more realistic approach for combining CO_2 mitigation and fuelwood production. For a project developer that initiates a carbon forestry project on general land in East Shinyanga, good forest management is a necessity to maximize income from carbon trade. However, as indicated before, in Shinyanga almost all land is used for grazing. General land might lack an official private owner; it still falls under local customary law, which is recognized by the national government. In order for a carbon forestry project to be successful, the local population has to be involved and experience direct benefits. This means that the livestock factor has to be taken into account and cattle has to be allowed in the woodland after the trees reached a certain size. Closing down the area for livestock is not likely to be accepted by local communities and will block the necessary local support for a forestation project (Mashaka 2007; Rubanza 2007).

Forestation on degraded grasslands can significantly improve fodder production, not only in quantity, but foremost in quality, since different fodder resources like leaves and pods become available (Barrow 1996; Rubanza *et al.* 2006; Rubanza 2007). Additional woodland benefits for local communities can be medicines, mushrooms, meat, gum, honey from bee-keeping, etc. (Monela *et al.* 2005). To fulfil goals for sustainable development, the woodland can become a sustainable source of fuelwood for a local community. To achieve this, the economic feasibility of carbon credit trading should allow for a part of the annual biomass increment to be reserved for controlled fuelwood production, instead of generating carbon credits, in a similar way as the large-scale afforestation project in the south of Tanzania, described previously (UNFCCC 2007a). However, for this purpose the project should have an attractive return on investment for the investor. In this way, fuelwood is produced from the 'big heap' in a controlled way. This is in contrast with smallholder-based tree planting were fuelwood production depends on the decisions made by individual smallholders. A carbon woodland on general land might provide several benefits for a local community, including employment. In return, the community can provide protection of the forest under local by-law. However, it is questionable if these benefits outweigh the investment and transaction costs related to such a project, especially in semi-arid regions, where growth rates are generally low and risks of fire and destruction by cattle are high. The methodology used to determine the economic feasibility of carbon forestry is presented in paragraph 4.3.

3.2 Rotational woodlots

Agroforestry is a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable by farmers (Nair, 1979 in (Msuya *et al.* 2006). As indicated in the previous chapter, various agroforestry technologies are increasingly adopted in Shinyanga for the purpose of improving fuelwood supply, fodder production and combating soil degradation. For each purpose, different tree species are preferred by local smallholders (HASHI 1998). In this way, not only land utilization can be optimized, but labour utilization as well. As indicated in the previous chapter, for smallholders labour capacity in Shinyanga is more a constraint than land capacity. Smallholders have a limited labour capacity, which limits them in generating income and thus their labour productivity should be maximized. When combining tree planting with crop production on one area of land, land preparation, weeding and manuring efforts benefit both trees and crop production, which maximizes the efficiency per unit of labour (Bakengesa 2007).

When agroforestry is focussed on wood production, short rotation woodlots with fast-growing tree species are practised (Chamshama *et al.* 2006). Rotational woodlot technology involves growing of trees and crops on farms in inter-related phases. Three phases can be distinguished in this system: The tree establishment and intercropping phase, the tree fallow phase and the cropping phase. During the first phase, trees and crops are planted. After 2-3 years of tree growth, the tree crown cover starts to block too much sunlight and tree roots compete too much with crops, which causes crop yields to become uneconomical. In this phase the area is left fallow and cattle is allowed to graze. At the start of the last phase, the trees are harvested and crops are planted in between the tree stumps. Coppice shoots are pruned so that a single new stem is growing (Nyadzi *et al.* 2003), as shown in Figure 8. Trees not only have the capacity to provide wood and fodder, they can also function as a natural fertilizer by fixing nitrogen in the soil, which increases crop yields. Yields can thus be maximized by using smart combinations of trees and crops.

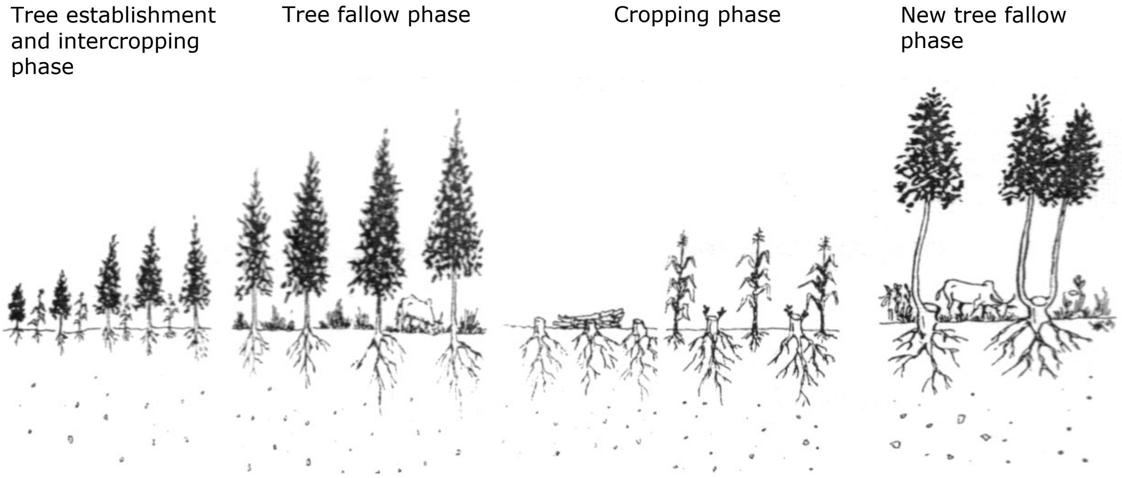

Figure 8: Management phases of rotational woodlots. Source: (Nyadzi *et al.* 2003).

Like all organisms, trees are following a logistic growth pattern over their lifetime. In theory, the optimal rotation period that maximizes wood yield is achieved when the annual growth increment is equal to the mean growth increment over the growing period. In this way the mean growth increment can be maximized over successive rotations. However, in practise this is almost never applied, especially not by smallholders (Malimbwi 2007). When expressing the produced wood in a monetary value, a social discount rate can be included in the logistic growth function. This social discount rate indicates the time preference of smallholders for making a profit. A high social discount rate causes the optimal rotation period to be significantly shorter, as pictured in appendix C. The methodology used to determine the costs and benefits of rotational woodlots is presented in paragraph 4.4.

3.3 Jatropha oil production

Alternatively to the previous options, it might be feasible to replace woodfuel by an alternative energy carrier. Kerosene is commonly used as a cooking fuel in urban areas. However, the cost of kerosene is significant. In rural areas, kerosene is only used for lighting, if available at all. Biofuels are a hot topic and momentarily the centre point of the debate on sustainable energy production. However, this debate is primarily focussed on the potential of biofuels to abate greenhouse gas emissions and their economic feasibility on the world market. Yet, there is relatively little focus on the potential of biofuels as an alternative energy and income source for local economies in developing countries. In Sub-Saharan Africa, the possibility of producing biofuels from the shrub *Jatropha Curcas L.* (hereafter named as Jatropha), or physic nut, is increasingly becoming under attention and is by many regarded as a promising alternative for rural communities (Openshaw 2000; Henning 2003; Del Greco *et al.* 2005; FACT 2008; TaTEDO 2008). Jatropha and its fruits are non-edible and Jatropha can grow on marginal land. It is claimed that this combination is ideal for preventing competition with food production, one of the main negative side-effects of modern bio-energy production, which makes Jatropha a favourable bio-energy source (FACT 2008). On the other side, all the attention has led to a hype of the Jatropha shrub, its potential yields and its presumed positive effects on rural livelihoods, which is not yet validated by facts (Jongschaap *et al.* 2007).

Jatropha is a perennial shrub that is originating from tropical America, but now thrives in many parts of the (sub)-tropics of Asia and Africa. Jatropha is a versatile shrub. It is traditionally known for its medicinal value and because its leaves and fruits are poisonous, it is widely used for protective hedges around fields to prevent browsing cattle and other animals from destroying the crops (Openshaw 2000). Besides animal barriers, Jatropha hedges are also used for preventing soil erosion and land degradation. In East Shinyanga, especially in the dry Meatu district, Jatropha is used in hedges as well (Mashaka 2007).

Jatropha is a fast-growing shrub that can grow up to 6 metres and has a lifespan of about 50 years. It is presently still a wild plant that is not cultivated through variety research (FACT 2006). In its natural distribution area, Jatropha grows in arid or semi-arid regions. It needs a minimum of 600 mm of rain annually to be productive, but is able to withstand long droughts, in which it sheds its leaves (Openshaw 2000). Jatropha forms a tab root which is retrieving nutrients from deeper soil layers. As a result, Jatropha grows relatively well on poor soils and on land suffering from land degradation. It is reported that Jatropha is suitable for reclaiming marginal land were crop cultivation is not possible and convert it into arable land. However, the oil seed production under marginal conditions is not yet validated (Jongschaap *et al.* 2007).

Jatropha produces fruits which contain three seeds. These seeds contain about 38% of non-edible oil, on a weight basis. This oil can simply be extracted by cold pressing, using a manual ram press, as shown in Figure 9. However, the oil extraction rate of this type of press is generally low. Mechanic oil expellers have significantly higher oil extraction rates, but against much higher investment costs

(Henning 2003). The remaining seedcake is an excellent organic fertilizer. One tonne of seedcake applied to the soil is equivalent to applying 0.15 tonne of NPK. Since Jatropha is not a nitrogen fixing plant, it is recommended to use the seedcake as a fertilizer (Openshaw 2000; Ghosh *et al.* 2007). The fruit hulls can also be used as a fertilizer.

Figure 10: Jatropha fruits in various stages including a cross-cut, showing the seeds. Source: (FACT 2006).

Figure 9: Jatropha oil extraction using a Bielenberg ram press. Source: (FACT 2006).

Because of its high viscosity, Jatropha oil cannot be instantly used as a fuel in diesel engines, oil lamps or cooking stoves. It is possible to adjust the equipment to run on Jatropha oil, or adjust the oil to run on conventional equipment. However, the extracted oil needs to be purified first. This can be done by a simple filtration and sedimentation process, in which seed residues are filtered out (Henning 2003). Diesel engines can be adjusted to run on pure Jatropha oil by using a dual-tank system so that the engine can be started with conventional diesel. Another option is pre-heating the oil (van Eijck 2007b). Furthermore, Jatropha oil can be blended with diesel. A blend of 20-30% Jatropha oil can still be used in a conventional engine (Pramatik 2003). Finally, Jatropha oil can be converted to biodiesel by the chemical process of transesterification. In this process, Jatropha oil is mixed with methanol and caustic soda. However, such a process is rather capital intensive and can only be realized on a larger scale (Henning 2003; van Eijck 2007b).

For household applications like cooking and lighting, solutions towards the use of Jatropha oil are hardly available, though several initiatives are undertaken. Due to its high viscosity, Jatropha oil cannot be used in conventional kerosene fuelled wick stoves. Bosch Siemens and the University of Hohenheim, Stuttgart, Germany, have recently developed a plant oil stove for use in developing countries. This concept is based on pressurized plant oil so that its viscosity is decreased (Kratzeisen *et al.* 2007) (See appendix A). A major advantage of a plant oil stove is the fact that unhealthy smoke is avoided. However, the disadvantages of a pressurized system are the relative high cost and high maintenance requirements. Bosch Siemens did several field studies on this stove, of which one was in Tanzania, though the outcome of this field test is unclear. Still, this seems to be the most realistic available plant oil stove for developing countries. Momentarily, the only lighting solution for Jatropha oil is a floating wick lamp. However, such a lamp does not give more light as a candle. Finally, Jatropha oil can quite easily be converted into high quality soap by cooking with caustic soda and water (Henning 2003).

A Jatropha plantation can best be established by raising seedlings. Alternatively, Jatropha can be grown directly from seeds or even from cuttings. However this is increasing the chance of mortality and is likely to result in lower seed production. To maximize seed production, the amount of branches should be increased by a pruning scheme in the first years of the plantation establishment. In this way the Jatropha shrub expands not in height, but in width and forms a bush shape, which is also favourable for fruit collecting (Mshanga 2007). Intensive irrigation is not needed and will mainly lead to an increase in leaves instead of fruits. Fertilizer should be applied annually to sustain optimal seed yield. Seed yields are only expected in year 3-4 and will reach a maximum in year 8-10. During the first five years of a Jatropha plantation, the Jatropha shrubs are small enough to allow intercropping of understory crops, like beans or unions (Mshanga 2007).

There is no clear harvesting season for Jatropha, as Jatropha continuously yields ripe nuts. Potential seed yields strongly differ per location. The plant might be able to survive in marginal areas, but this does influence the potential oil yield. Jatropha seed yields have been exaggerated in the past; thereby interpreting maximum yield potentials as expected yields. Yield potentials range from 0.4–12 tonne per ha after five years of growth (Openshaw 2000). In Tanzania, estimated yields are 4 kg per tree in fertile areas to 1.5-2 kg per tree in dryer areas, like semi-arid Shinyanga (van Eijck 2007b).

As indicated before, many areas in Shinyanga are so remote that market access is a constraint and kerosene is not available, let alone that there is a market for Jatropha oil. In these areas, self sufficiency of energy could be a reason for farmers to grow Jatropha. Alternatively, smallholders in Shinyanga can sell the produced seeds to Diligent. In this research, all the options as indicated above: Cooking, oil trading, soap production, electrification and seed trading will be included. The methodology to do this is explained in paragraph 4.5.

3.4 System Comparison

In the previous sections, the general concept of the three biomass energy supply systems was described. A few fundamental points of difference between these systems, adopted in East Shinyanga can be identified. These are summarized in Table 5:

Parameter	Carbon forestry	Rotational woodlot	Jatropha oil production
Investment cost	High	Low	Low
Initiator	Investor	Smallholder	Smallholder
Relative size	Large	Small	Small
Land use	General land	Private land	Private or general land
Baseline land use	Grazing	Agriculture and grazing	Agriculture and grazing or only grazing
Lifetime	Crediting period	Per rotation	Jatropha lifespan
Relative energy production per ha	Low	High	High

Table 5: Overview of main characteristics of the three biomass energy supply systems in semi-arid Shinyanga.

In practice, fuelwood production from carbon forestry fundamentally differs from the other two systems, since carbon forestry includes high fixed investment costs and therefore a relatively large land area is needed to create enough benefits to earn back the expenses. Therefore, such a project will only be initiated by an external investor. Sustainable fuelwood production from carbon forestry is most feasible on general land for reasons given in section 3.1.3. In the absence of this project this general land would be used for cattle grazing.

Rotational woodlots and Jatropha plantations have relatively little fixed investment costs and can thus easily be initiated on a small scale by single smallholder farmers. There are also differences in land use. Rotational woodlots are most likely to be established on smallholder agricultural land, because of the combination of crop farming and short rotation tree growing. Smallholders, who aim to maximize their profits, would not be interested in cultivating marginal general lands which are likely to give lower crop yields. Furthermore, one of the benefits of rotational woodlots is the potential to increase soil fertility and combat agricultural land degradation. In the absence of a rotational woodlot, the land is most likely to be used for agriculture during the wet season and grazing during the dry season.

Compared to a rotational woodlot, a Jatropha plantation would be established for a much longer time span and intercropping benefits are relatively less important since this is only possible in the first few years. Furthermore, Jatropha performs relatively well on marginal land. For these reasons, such a plantation could be established either on arable, agricultural land, or on unused marginal land. The latter does not have to be claimed general land per se. Because of overexploitation, smallholder agricultural land can as well be degraded to such an extend that it cannot be used for agriculture anymore (Monela *et al.* 2005). However, as indicated in the previous chapter, little is known about seed yields in semi-arid regions on arable land or on marginal land and data of Jatropha yields on different soil qualities is lacking.

As indicted before, Shinyanga has the largest land ownership in Tanzania, in terms of hectares per household. Because of the climatic conditions, yields are generally low and farmers are forced to cultivate larger areas of land, which results in a labour constraint on their production and low returns on labour. The pressure on land is originating not so much from agriculture, but from the enormous livestock concentration in semi-arid Shinyanga. Thus, Jatropha cultivation on marginal land might avoid competing with food crops on arable land, but it would compete with cattle grazing and thus increase grazing pressure. Furthermore, this competition with food crops on arable land might be limited, since farmers mainly face a labour constraint and not so much a land constraint. In more fertile areas with a high pressure on agricultural land, like Kilimanjaro region in the north of Tanzania, the benefit of growing Jatropha on marginal land might be more significant. At last, farmers that would engage in Jatropha cultivation are not likely to belong to the poorest wealth group. Comparable to farmers that start rotational woodlots, such farmers are likely to own excess arable land and resources, which allows them to invest in a new crop and take some risks. Such farmers would plant Jatropha on available land where the highest yields are expected and these are not likely to be marginal lands.

As indicated in the previous chapter, communal land is disappearing in Shinyanga, because of the rapid population increase. What is left is generally used for *Ngitili* (Mlenge 2007). Thus, this land is not likely to be available for bio-energy production.

4. Methodology

In the first section of this chapter, the general methodology for this cost/benefit analysis is explained. The biomass energy supply systems are compared to a baseline scenario, which is identified in the next section. Finally, the three biomass energy systems are identified in detail and the methodology for determining costs and benefits is explained.

4.1 General methodology

The economic feasibility of the three alternative household biomass energy supply systems is analyzed, relative to a baseline situation, over a time span of multiple years. Despite the differences between the three systems, a comparative cost/benefit analysis is still possible, based on the Net Present Value (NPV) per hectare, the Return on Labour and the production cost of the produced biomass energy: The Cost of Energy of the three systems. The total area (in ha) is thereby used as an input variable.

All monetary values are expressed in US$ since this currency is widely used in Tanzania. Furthermore, unless indicated otherwise, 2007 monetary values are used. Historical monetary values in Tanzanian Shelling (Tsh) were first corrected to 2007 values using the Consumer Price Index (CPI) of Tanzania (USDA 2007). A CPI was preferred since this better indicates changes in consumer prices, while a GDP deflator only corrects for inflation. Next, Tanzanian Shillings were converted to US Dollars using the average currency conversion rate over 2007 (1 US$ = Tsh 1.205). The average currency conversion rate for Euros over 2007 is 1 US$ = € 0,731 (OANDA 2008). To analyse the sensitivity of the results, sensitivity analyses are performed on the most important parameters of each system.

4.1.1 The Net Present Value (NPV)

The NPV indicates the overall economic feasibility of each system over its life span. This is calculated by determining the overall discounted net costs and benefits, compared to a baseline, which is used as a reference. Since the net benefits of the baseline are foregone by starting a system on an area of land, these are deducted from the benefits of the system and are thus regarded as opportunity costs in this research. By applying this approach, the NPV of the baseline becomes 0, compared to the NPV of each system. The following general formula will be applied (Blok 2006):

$$NPV = \sum_{t=o}^{n} \frac{B_t - C_t)}{(1+d)^t} \qquad \text{(Formula 1)}$$

In which:
B_t = Total benefits of a project in year t
C_t = Total costs of a project in year t
d = Real discount rate (corrected for inflation)
n = lifetime of the project

4.1.2 The Return on Labour

The Return on Labour is the average discounted financial benefit per unit of labour input over the project lifetime. Cost, benefits and labour intensity differ per year. For instance, in the first years investment costs and labour intensity might be high, while benefits are not available yet, so that the annual return on labour is negative in these years. To determine the overall Return on Labour, the total net benefits of the project cannot just be divided by the total labour, since benefits in for example year 10 have a different present value as benefits in year 2, as shown in formula 1. Consequently, labour exercised in year 10 has also a different present value as labour exercised in year 2. Therefore the present value of the average Return on Labour is determined as follows:

$$RL = \frac{\sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+d)^t}}{\sum_{t=0}^{n} \frac{L_t}{(1+d)^t}} \qquad \text{(Formula 2)}$$

In which:
RL = The Return on Labour (US$/man-day)
L_t = The labour input in year t (man-days)

It seems awkward to discount over non-monetary goods like labour; however, the labour itself is not discounted, but the value of labour. This value of labour is also the object that is calculated and is thus assumed to be a constant over the project. The Return on Labour is thus merely an economic construction to allow comparison, instead of being a real wage that is obtained from each day of work.

4.1.3 The production cost of biomass energy

The production cost of household biomass energy is best expressed in both physical units (e.g. headload of fuelwood, litre of Jatropha oil) and in energy units. When expressed in energy units, I separate between GJ of primary energy and GJ of utilized heat. The latter thus includes the efficiency and cost of the cooking stove, as shown in formula 3. This is done, because it better indicates the real cost of energy and allows for a better comparison of different energy carriers. The cost of energy is determined as follows:

$$COE_h = \frac{\sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+d)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+d)^t}} * \frac{1}{\eta_{stove}} \qquad \text{(Formula 3)}$$

In which:
COE_h = The production cost of utilized heat (US$/$GJ_H$)
E_t = The total biomass energy produced (GJ)
η_{stove} = The efficiency of the cooking stove

Again, the value of the total energy production is discounted. The specific cost of energy is being calculated and is thus assumed to be a constant over the lifetime of the project. It is not possible to calculate the cost of energy per year, since there is a time lag between investment, labour costs and energy production.

4.2 Baseline assessment

In order to determine the economic feasibility of the three biomass energy systems, first the baseline needs to be assessed. The baseline is translated into the opportunity cost of land, the shadow cost of labour and the shadow cost of energy.

4.2.1 The opportunity cost of land

The opportunity cost of land is equal to the production of land in the absence of the project (Mishan *et al.* 2007). In this research, for simplicity, available land is divided into two groups: Arable land that can be used for agriculture during the wet season and grazing during the dry season and marginal land that can only be used for grazing. The latter can be general land or degraded agricultural land. As indicated before, agricultural land is often rented in rural Shinyanga. At the start of the growing season, poor farmers that need land for cultivation can rent land from richer farmers with excess land. After the end of the growing season, pastoralists in need for fodder for their cattle can rent agricultural land for grazing. Therefore, it is assumed that agricultural land will be rented out for agriculture during the wet season and grazing during the dry season, if it would not be utilized by the owner. Often, land renting is paid in natural payments; however, cash payments are also possible. This monetary renting price is assumed to be the opportunity cost of land. However, agricultural land cannot be cultivated every year, since the soil will become depleted and yields will decrease. Ramadhani surveyed farmers in the neighbouring Tabora region and found that smallholder farmers practised 3 years of fallow after 2 years of maize cultivation (Ramadhani *et al.* 2001). It is assumed that this applies for smallholders in Shinyanga as well. Thus, it is assumed that agricultural land can only be rented out for cultivation during the wet season in 2 out of 5 years, while it can be rented out for grazing during the dry season every year.

In case of marginal land, be it privately owned or claimed general land, the opportunity cost is assumed to be equal to only the seasonal grazing rent price, since all land is used for grazing in Shinyanga. In reality, the land rent price is strongly depending on the quality of the land and thus differs per area. However, for simplicity, it is assumed that the seasonal grazing rent price is equal for agricultural land and marginal land. A small survey was done in four villages around Shinyanga town, in order to determine various input data needed for this cost/benefit analysis, including land rent prices (see appendix D). Furthermore, two agricultural land rent prices in rural Shinyanga were obtained from literature, as shown in Table 6. For this research, the average value is assumed to be the opportunity cost of agricultural and grazing land.

Village	**District**	**Renting cost of land (US$/ha/season)**		**Source**
		Agriculture $C_{land,agro}$	Grazing $C_{land,gr}$	
Samuye	Shinyanga rural	41,02	16,60	Survey appendix D
Mwamala	Shinyanga rural	20,51	16,19	〃
Usanda	Shinyanga rural	41,02	15,19	〃
Mwamnemha	Bariadi	29,53	-	(Monela *et al.* 2005)
Buzinza	Kishapu	36,92	-	(Msuya *et al.* 2006)
AVERAGE		**33,80**	**15,99**	

Table 6: Renting cost of land for agricultural and grazing purposes in rural Shinyanga.

4.2.2 The shadow cost of labour

As indicated in the previous chapter, the cost of labour is hard to define in rural Shinyanga, since land workers are often paid in natural payments, like food or land. There is a newly established official Tanzanian minimum wage rate of Tsh 80.000 per month (Morogoro 2007), which is Tsh 3.682, or US$ 3,06 per man-day, but this is not often applied in rural areas and therefore, using the official minimum wage rate as a proxy for the wage paid to land workers is too optimistic (Bakengesa 2007). Monela proposed to use half the official minimum wage rate as a proxy for the shadow cost of labour (Monela 1989 in (Kihiyo 1996)), which would result in a shadow cost of US$ 1,53 per man-day.

The shadow cost of agricultural labour is not always equal to the return on agricultural labour. The return on labour expresses the financial benefit per unit of labour and is obviously higher for a land owner as for a landless farmer who has to rent land and thus has higher costs. The shadow cost of labour is equal to the marginal rate of production of the worker in the absence of the project (Mishan *et al.* 2007) and is assumed to be equal for the landless farmer and the landowner. In this research, I assumed that the shadow cost of labour is the return on labour minus the opportunity cost of land. This is based on the assumption that in the absence of the project, at the start of the wet season, a land owner can choose to use his land for cultivation of maize or he can rent it out. In case he would cultivate the land without investing any labour himself, he has to attract land workers to do all the work. In that case, the land owner will pay the land workers a wage which would still leave him with a benefit equal to the opportunity cost of the land, which is the land rent price for agriculture during the wet season.

The shadow cost of labour is an important parameter for this cost/benefit analysis, since the proposed biomass energy projects are rather labour intensive. Therefore, I decided to further determine the shadow cost of agricultural labour by looking at the economics of the most common agricultural activity in semi-arid Shinyanga: Maize production. The following formula was used:

$$W_{sh,agro} = \frac{(Y_{maize} * P_{maize} - C_{maize} - C_{land,agro})}{L_{total}} \qquad \text{(Formula 4)}$$

In which:
$W_{sh,agro}$ = The shadow cost of labour in the agricultural sector (US$/man-day)
Y_{maize} = Average maize yield (tonne/ha/year)
P_{maize} = Market price of maize (US$/tonne)
C_{man} = Total management costs for maize cultivation (US$/ha/year)
$C_{land,agro}$ = Land rent price for agricultural land (US$/ha/year)
L_{tot} = Total annual labour needed (man-days/ha/year)

I used three different case studies, in which the return on labour of smallholder maize production was analyzed: One in Maswa District, Shinyanga (Mdadila 1998 in (Limbu 1999)), one in the Lake Zone (Van der Linde *et al.* 1998 in (Limbu 1999)) and one in Tabora region, which is bordering Shinyanga region (Ramadhani *et al.* 2001). I calculated the return on labour and the shadow cost of labour for each study, using a present average maize yield, a present market price in East Shinyanga and the opportunity cost of land as presented in Table 6. The management costs were converted to 2007 values. Van der Linde *et al.* analyzed the return on labour both for cultivation using a hand hoe and using an ox and plough. Ox ploughing is often practised in Shinyanga and oxen and ploughs can be rented by farmers who do not own cattle (Rubanza

2007).Therefore, I included ox-ploughing in my analysis (see appendix E). Ox ploughing strongly increases the return on labour, because land cultivation by hand hoe is labour intensive (Limbu 1999). Furthermore, other estimates on the shadow cost of land labour in Tanzania that could be found in literature and expert estimates were added. The average of all theses values was determined as an estimate of the return on labour and the shadow cost of labour for this analysis. The results are presented in Table 7:

Average maize yield	0.80 tonne /ha	(See appendix E)		
Average maize price	US$ 207,50 /tonne	(See appendix E)		
Study	**Management Costs (US$/ha)**	**Labour input (man-days)**	**Return on labour (US$/man-day)**	**Shadow cost labour (US$/man-day)**
Mdadila, 1998	61,73	74	1,41	0,95
Van der Linde, 1998 Hand hoe	9,39	90	1,74	1,36
Van der Linde, 1998 Ox ploughing	29,90	60	2,27	1,71
Ramadhani, 2001	71,64	44.5	2,12	1,36
Other estimates shadow cost of labour of land worker				
0.5 x official minimum wage rate (Monela 1989 in (Kihiyo 1996))				1,53
Tsh 2.000 /man-day (Bakengesa 2007)				1,66
Shadow cost of collecting various *ngitili* products: Tsh 1.768 /man-day (Monela et al. 2005)				1,47
AVERAGE			**1,88**	**1,43**

Table 7: Estimate of the Return on labour and the Shadow cost of labour (See Appendix E).

Subsistence agriculture is practised by both male and female members of the household, including children. Thus, the value of US$ 1,43 per man-day can be seen as an average for both sexes, but is likely to be higher for men. Furthermore, the shadow cost of labour might differ per month. During the sowing and harvesting season, when there is a high labour demand, it might be relatively high and during the agricultural off-season when land is not cultivated and employment is scarce, it might be much lower. However, to what extend this has an impact on the shadow cost of labour could not be determined and therefore it is assumed that the shadow cost of labour is constant throughout the year. The impact of the shadow cost of labour on the economic feasibility of the biomass energy projects will be evaluated by sensitivity analysis.

Thus, the shadow cost of labour is determined, based on the benefits of maize production and the renting price of agricultural land. In this research, The Net Present Value of maize production is defined as zero, since the labour, land and seed costs are exactly compensated by the benefit of selling maize. However, this is just a matter of definition, it does not mean that maize cultivation is not economical. Maize production will be the baseline scenario for this study, to which the three biomass energy systems will be compared.

4.2.3 The shadow cost of energy

Eventually, the proposed systems should provide rural households with sustainable biomass energy. However, these systems will only be adopted if they are more attractive compared to the baseline. Therefore, first the Cost of energy in the baseline situation should be determined. Fuelwood is by far the most important energy carrier in rural areas, followed by charcoal and kerosene, which is mainly consumed in urban areas. However, for comparison I will determine the cost of energy of multiple energy carriers in rural East Shinyanga. I will also include the option of cooking on electricity, in case TANESCO would start a rural electrification project in East Shinyanga. Because the cooking efficiency varies per energy carrier, I will express the Cost of energy both in units of primary energy and in units of utilized heat.

4.2.3.1 The shadow cost of fuelwood

Fuelwood is mostly collected from natural forests by women, who may spend several hours per day during the fuelwood collecting season. Bakengesa estimated that women spend on average 8 hours per day on fuelwood collecting during the fuelwood collecting months, which is about 3-4 months during the dry season. During these months, fuelwood is stacked at households for utilization during the wet season. It is further estimated that of these 8 hours, 5 are needed for travelling and 3 for picking branches (Bakengesa 2007). The National Household Budget Survey determined the average distance of households in Shinyanga to sources of fuelwood to be 4.2 km (NBS 2001). If a woman has access to a *Ngitili*, the time spend on fuelwood collecting can be significantly reduced (Monela *et al.* 2005). On the other hand, for many women the distance to natural forests is too large to walk. Fuelwood scarcity in Shinyanga has led to fuelwood commercialization. In 1998 it was surveyed that 62% of the population was buying fuelwood. However, buying fuelwood is more pronounced in municipal areas than in rural areas (HASHI 1998).

In case fuelwood is collected for 'free' from natural forests, the shadow costs of fuelwood is best expressed in the time spend by women on collecting fuelwood, which is the cost of the opportunity forgone: Women that spend time on fuelwood collecting cannot spend this time in an alternative way. Even when women would not work in the absence of the need to collect fuelwood, the shadow cost of fuelwood collecting would not be 0, since time spend on e.g. raising children or even resting has a certain value (Mishan *et al.* 2007). Another shadow cost is the increase in forest degradation, caused by continuous fuelwood harvesting, however this is beyond the scope of this research. For a woman who has access to a fuelwood market, the shadow cost of labour for collecting fuelwood is equal to the market price. This is simply understood by the fact that a woman who has no cash available and has to collect wood, has the opportunity to sell the collected wood or use it for her household. If she would be offered the market price for her fuelwood, she would be equal about these opportunities: There would be no extra benefit in selling, because she needs fuelwood anyway for her household. It would thus make sense to use the market price of fuelwood as a shadow cost. The annual average market price is estimated to be Tsh 600 per headload (US$ 0,50), based on an indicated range of Tsh 500 and Tsh 700 for the dry season and the wet season, respectively (See appendix D).

However, market prices are often bad indicators for the shadow cost of a good (Mishan *et al.* 2007), since the use of the market price of fuelwood is constrained by the market access. Image a woman who lives in a rural area where no fuelwood market is established. She has to spend 6 hours to collect a headload of fuelwood for her household. It is not likely that she would sell this headload for the market price of Tsh 600, since she needs the wood to cook and thus, at that moment, she attaches a greater value to the fuelwood as this market price indicates. In conclusion, the shadow cost of fuelwood is also depending on the market access.

In 2000, the IUCN did a survey in Shinyanga and valued the shadow labour cost per day for harvesting and transporting fuelwood by women to be Tsh_{2007} 1.100, or $\text{US\$}_{2007}$ 0,91 (Monela *et al.* 2005). However, it was not indicated how much wood is collected per day. Monela *et al.* did an economic valuation of subsistence products obtained from *ngitili* in Shinyanga. An hour of work spent by a woman on collecting forest products was valued to be $\text{US\$}_{2007}$ 0,183, which is US$ 1,47 for a labour day (See Table 7). Again, the quantity of fuelwood collected is not indicated so that the shadow cost per unit of fuelwood cannot be determined. However, clearly *Ngitili* lead to significant fuelwood improvements, considering the differences in shadow cost of labour of collecting fuelwood between the two studies.

In conclusion, it is not well possible to estimate the shadow cost of fuelwood, based on the opportunity cost of the time spent by women on collecting fuelwood in East Shinyanga, since there is lack of information on the average time needed for collecting a headload of fuelwood. Therefore, I will use the market price of US$ 0.50 per headload as a proxy for the shadow cost of fuelwood. The question remains: How much is a headload?

4.2.3.2 A headload of fuelwood

Tanzanians master the art of carrying goods on the head and fuelwood is no exception, which explains the, for Westerners 'exotic' unit of a headload of fuelwood. The size of a headload can differ significantly, depending on the age, strength and capability of the person that is carrying it. However, for this analysis, it will be more comfortable to express energy carriers in units of energy. Therefore, first the average weight of a headload was determined and next, the average energy content per unit of weight.

Average weigh headload (kg)	Source	Location
15	Survey appendix D	Shinyanga rural
13	Survey appendix D	Shinyanga rural
30	Survey appendix D	Shinyanga rural
30	(Ngaga 2007)	Tanzania
15 – 25	(Minja 2007)	Shinyanga
8 – 16	(HASHI 1998)	Shinyanga
18.6	(MNRT 2001)	Mbeya Municipality
14.4	(MNRT 2001)	Mwanza City
18.6	(MNRT 2001)	Dodoma City

Table 8: Average fuelwood headload weight as estimated or surveyed by various sources.

Table 8 indicates various estimates and surveys of the average fuelwood headload size. The value of 30 kg is likely to be exaggerated as an average. There will be women strong enough to carry this, but it is likely to be far above the average. I estimated the average headload to have a weight of 16 kg.

4.2.3.3 The average energy content of fuelwood

The energy content of wood differs strongly per tree specie. East Shinyanga is dominated by acacia tree species, of which *Acacia Nilotica* is commonly used for fuelwood. This wood has an energy content of 19.8 MJ per kg oven dry wood, which is wood with zero moisture content. However, wood burned by households is not likely to be oven dry, though households practise wood drying. Air dry wood in Tanzania commonly has a moisture content of 12% (Bryce 2003). The energy content can be converted for different moisture content, according to the following formula (Blok 2006):

$$E_{LHV,wb} = E_{HHV,dry} - h * E_{w,evap} * m_{H2O} * (1-w) - E_{w,evap} * w \qquad \text{(Formula 5)}$$

In which:
$E_{LHV,wb}$ = The lower heating value of the wood on a wet basis (MJ/kg)
$E_{HHV,dry}$ = The higher heating value of the wood on an oven dry basis (MJ/kg)
h = The fraction of hydrogen in the oven dry wood (0.0667 kg/kg)
$E_{w,evap}$ = The energy required for evaporation of water (2.26 MJ/kg at 25°C)
m_{H2O} = The mass of water created per unit mass of hydrogen (8.9 kg/kg)
w = the fraction of water in the wood on a wet fuel basis (12%)

The energy content of air dry *Acacia Nilotica* is found to be 15.9 MJ per kg. From the above, the cost per unit of energy is determined as follows:

$$COE_{fw} = \frac{(P_{hl} * 1000)}{(E_{LHV,wb} * M_{hl})} \quad \text{(Formula 6)}$$

In which:
COE_{fw} = The shadow cost of fuelwood (US$/GJ)
P_{hl} = The cost per headload of fuelwood (US$/headload)
M_{hl} = The average weight of a headload of fuelwood (kg/headload)

From this, the shadow cost of fuelwood is determined to be US$ 1,95 per GJ.

4.2.3.4 Energy consumption and demand

Since fuelwood consumption is by far the most dominant energy carrier, I determined the total energy consumption and demand in rural east-Shinyanga by analyzing the average fuelwood consumption. As indicated in the previous chapter, because of a fuelwood deficit, fuelwood consumption in East-Shinyanga is considerably lower as the Tanzanian average (see **Error! Reference source not found.** and Table 1). Limited data could be obtained about fuelwood consumption in Shinyanga:

Location	Fuelwood consumption (tonne/capita/year)	Fuelwood demand (tonne/capita/year)	Source
Samuye	0.24	0.36	Survey, see appendix D
Mwamala	0.18	0.37	
Usanda	0.42	0.83	
Old Shinyanga	1.23	2.46	
Average	**0.52**	**1.00**	
East-Shinyanga	0.56	1.60	(Kaale *et al.* 1985)
West-Shinyanga	1.44	1.60	
Assumption	**0.55**	**1.20**	

Table 9: Fuelwood consumption and demand estimate in East Shinyanga. Annual per capita fuelwood consumption was determined by using an average headload weight of 16 kg. Wood consumption in cubic meters was converted to tonnes assuming an average wood density of 0.80 tonne dm/m^3, based on the species *Acacia Polyacantha* and *Acacia Nilotica* (ICRAF 2008).

Table 9 indicates that fuelwood consumption differs significantly per area in East Shinyanga. However, the average surveyed fuelwood consumption in the villages in Shinyanga Rural district is almost equal to the fuelwood consumption as surveyed in 1985 by Kaale *et al.* They further estimated that people in East Shinyanga would almost triple their consumption if wood would be readily available. However, it was indicated by the surveyed people in Shinyanga Rural district that they would double their consumption. The latter is also estimated by professor Ngaga (Ngaga 2007). Based on this, I estimated the fuelwood consumption to be 0.55 tonne dm/capita/year, which would more than double to 1.20 tonne dm/capita/year in case wood would be readily available. The average household size in Shinyanga is 6.7 persons (NBS 2001), thus the annual household fuelwood consumption and demand is 3.70 tonne and 8.04 tonne, respectively.

As in the rest of Tanzania, fuelwood conversion efficiency in East Shinyanga is low, despite the large deficit. Bakengesa estimated that 5–10% of the population is using improved cooking stoves (Bakengesa 2007), instead of conventional 3-stone stoves. Assuming an average efficiency of 7% for 3-stone stoves (see Table 2) and an average efficiency of 20-25% for improved mud stoves (See appendix

A), the overall estimated average fuelwood cooking efficiency in East Shinyanga is 8%. Based on the per capita fuelwood consumption and demand as estimated above, the average cooking energy consumption and demand can be expressed in terms of primary energy E_{prim} and utilized heat E_{heat}. The latter is determined by dividing the primary energy consumption by the average cooking efficiency:

Energy	**Energy consumption (GJ/capita/year)**	**Energy demand (GJ/capita/year)**
Primary energy E_{prim}	8.77	19.13
Utilized heat E_{heat}	0.72	1.56

Table 10: Energy consumption and demand in East Shinyanga, expressed in GJ. Wood was converted to energy by using an energy content of 15.9 MJ/kg.

4.2.3.5 The cost of charcoal

Charcoal is mainly produced in the vicinity of, and consumed in urban areas. However, it is favoured above fuelwood in rural areas as well, because it is much more comfortable to use as a cooking fuel. As indicated in the previous chapter, two qualities of charcoal exist, Miombo charcoal transported from West Shinyanga and Tabora region and local acacia charcoal. For this calculation, I will only analyze the latter, since this allows better comparison of charcoal produced from rotational woodlots in East Shinyanga. Most charcoal is produced and transported illegally. Therefore I will calculate the cost of both legal and illegal charcoal similarly to formula 6:

Parameter	**Value**	**Source**
Energy content charcoal	32 MJ/kg	(Rosillo-Calle et al. 2007)
Cost of charcoal bag farm-gate	Tsh 5.000 (US$ 4,15)	Survey, see appendix D
Weight of bag	29 kg	Survey, see appendix D
Farm-gate price illegal charcoal	**US$ 4,47/GJ**	
Annual government registration fee	Tsh 200.000/yr (US$ 166)	(Maganga 2007)
Assumed charcoal production producer	700 bags/year	Assumption: ≈2 bags/week
Payable fee	Tsh 2.000/bag (US$ 1,66)	(Maganga 2007)
District Council fee	Tsh 200/bag (US$ 0,17)	(Maganga 2007)
Farm-gate price legal charcoal	**US$ 6,70/GJ**	

Table 11: Input data for computing the cost of charcoal per unit of energy.

The cost is based on the farm-gate price per bag of charcoal as indicated by a charcoal dealer in Shinyanga town, because it is assumed that the rural purchase price for charcoal is equal to the farm-gate price. Table 11 indicates that legal charcoal is considerably more expensive, compared to illegal charcoal. However, this is for farm-gate prices. In Shinyanga town, the purchase prices for illegal and legal acacia charcoal are Tsh 7.500 (US$ 6,23) and Tsh 9.000 (US$ 7,47), respectively (see appendix D).

4.2.3.6 The cost of kerosene and electricity

Kerosene is used as a cooking fuel in urban areas. In rural Shinyanga it is only used for lighting. The cost per unit of energy in rural Shinyanga is shown below:

Parameter	**Value**	**Source**
Market price of kerosene	Tsh 1.500/litre (US$ 1,25)	Survey, see appendix D
Energy content kerosene	43.7 MJ/kg	(Blok 2006)
Density kerosene	0.78 kg/litre	http://www.engineersedge.com/fluid_flow/fluid_data.htm
Cost of kerosene $C_{E,ker}$	**US$ 36,53/GJ**	

Table 12: The consumer market price of kerosene in rural Shinyanga in units of energy.

Rural electricity is practically non-existent in Shinyanga. However, in case TANESCO would start a rural electrification project, the option for cooking on electricity will arise. The cost of electricity is a bit more complicated compared to the previous energy carriers, since initial investments are needed to obtain access to electricity. TANESCO will provide power generation and a small grid, but to obtain connection to this grid, a connection fee has to be paid. After connection to the grid, electricity can be used for a fixed rate. However, because rural electrification is subsidized, these prices do not reflect the real cost. I applied the following formulas based on (Blok 2006):

$$COE_{elec} = \frac{C_{TAN}}{\eta_{stove,e}} + \frac{(\alpha * I + C_{service})}{E_{heat}} \quad \text{(Formula 7)} \qquad \alpha = \frac{d}{1-(1+d)^{-L}} \quad \text{(Formula 8)}$$

In which:
COE_{elec} = The total cost of electricity (US$/GJ)
C_{TAN} = The fixed TANESCO price of electricity (US$/GJ)
α = The capital recovery factor (year^{-1})
I = The initial investment (connection fee) (US$/HH)
$C_{service}$ = The annual service costs (US$/HH/year)
$\eta_{stove,e}$ = The electric cooking stove efficiency
E_{heat} = The annual utilized heat per household (GJ/HH/year)
r = The real discount rate (corrected for inflation)
L = The payback time of the investment (years)

The electric cooking efficiency and the cost of the stove (see table 14) can be excluded from formula 7 when calculating the cost of energy. These are only needed for calculating the cost of utilized heat. For calculating the cost of electricity, I used the following input data:

Parameter	Value	Source	Remarks
Price of electricity	US$ 0,088/kWh	(Semsella 2007)	General usage tariff
Off-grid connection fee	US$ 204,18/HH	(Semsella 2007)	
Service charge	US$ 1,57/month	(Semsella 2007)	
Efficiency electric stove	68%	Own experiment	See below[1]
Annual heat demand E_{heat}	10.5 GJ/HH/year		6.7 persons per household
Discount rate	16.4%	(Bank of Tanzania 2008)	Average over period 12-2004 – 4-2007
Inflation rate	4.6%	(Bank of Tanzania 2008)	Average over period 2002 - 2006
Payback time connection	10 years	Assumption	
Cost of electricity	**US$ 26,88 /GJ** **US$ 0,097/kWh**		
Cost of utilized heat	**US$ 42,32 /GJ**		

Table 13: Input data for determining the cost of rural electricity in East Shinyanga in the baseline situation.

The real discount rate, corrected for inflation is determined to be 16.4 – 4.6 = 11.8%. This rate will be used as a standard from now on.

4.2.3.7 End-use efficiency and cost

As indicated before, to calculate the real cost of cooking per energy carrier, the cost of utilized heat is a better indicator. Therefore the efficiency and cost of cooking stoves should be included. In order to identify energy saving options in the baseline and to compare the biomass energy produced in the proposed

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[1] The efficiency of the electric cooking stove was determined by repeatedly boiling 3 litres of water in an aluminium pan with a closed lid, while measuring the temperature and the electricity consumption.

systems with these energy saving options, I included both conventional and improved fuelwood and charcoal stoves (See appendix A):

Energy carrier	**Stove type**	**Efficiency**	**Cost (US$)**	**Lifetime**	**Source**	**Cost of energy C_{heat} $(\text{US}\$/\text{GJ}_H)$**
Wood	3-stone stove	7%	free	-	See Table 2	27,89
	mud stove	22.5%	1,43	2 months	(Pesambili 2007)	9,28
	burnt brick stove	29%	33,20	5 years	(Malimbwi *et al.* 2007; Pesambili 2007)	7,22
Charcoal	Traditional stove	16.5%	1,66	3 years	(Malimbwi *et al.* 2007; Pesambili 2007)	35,21 Legal 21,73 Illegal
	Double ceramic liner stove	45%	8,00	3 years	(Pesambili 2007)	13,02 Legal 8,08 Illegal
Kerosene	kerosene stove	46%	12,45	5 years	(Anozie *et al.* 2007)	95,43
Electricity	Electricity stove	68%	49,80	5 years	Own experiment	42,32

Table 14: Costs, efficiencies and lifetimes of various cooking stoves and the related cost of energy in terms of utilized heat.

I assumed that the electricity stove and the burnt brick stove are too expensive to pay of directly so that a loan is needed. The capital recovery factor for these stoves was determined as in formula 8. For the other stoves, the annual investment costs are determined by simply dividing the cost over the lifetime of the stove. The annual consumption of charcoal and kerosene was determined by dividing the annual heat demand E_{heat} by the stove efficiency. Figure 11 shows the cost of energy of the different carriers, both in primary energy and utilized heat, in order of magnitude.

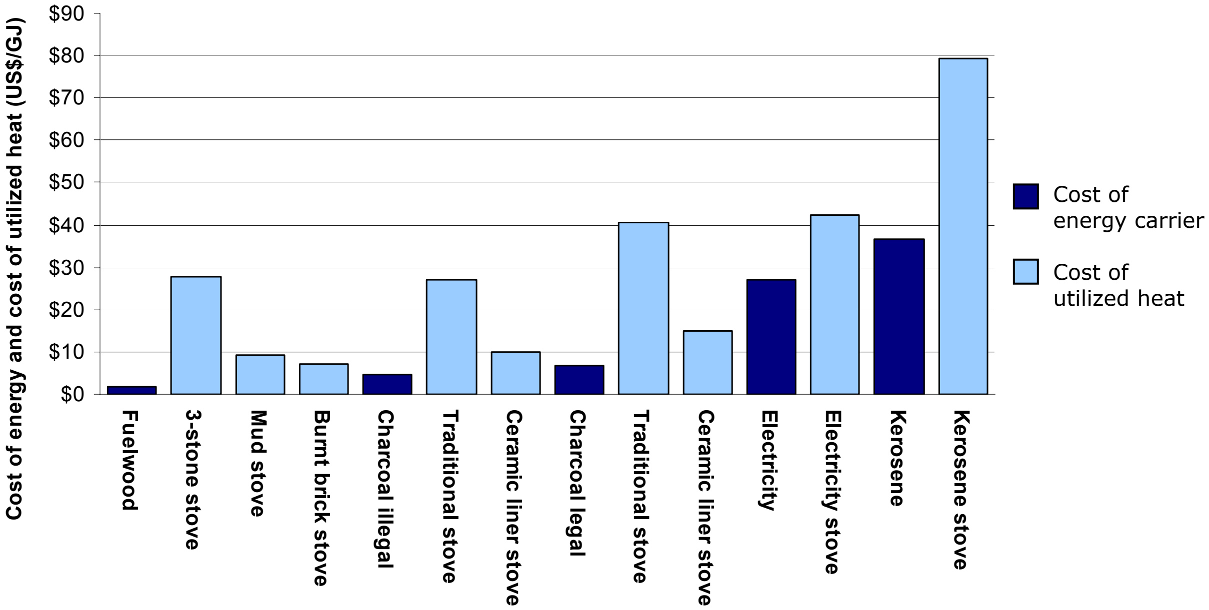

Figure 11: Cost of energy for household cooking in rural East Shinyanga, both in terms of primary energy (dark blue columns) and utilized heat (light blue columns), using various cooking stoves. The cost of energy carriers in terms of primary energy is shown in order of magnitude.

Figure 11 illustrates the large gap between the cost of woodfuel and the cost of fossil energy sources. Even when converting for the cost of utilized heat, fossil sources are significantly more expensive. There is a large gap in the cost of utilized heat between legal and illegal charcoal. Remarkably, the most utilized cooking technique, fuelwood on a 3-stone stove, is relatively expensive. Furthermore, cooking with charcoal on a ceramic stove, which is much more attractive as using fuelwood, has about the same total costs as cooking on fuelwood on a mud stove. This is caused by the high efficiency of ceramic charcoal stoves. Though, the former needs cash investments and the latter does not. Investing in improved stoves significantly lowers the cost of cooking. The share of stove investment costs per GJ heat is so low for all stove types that it would hardly be visible on this graph. Most economical is using fuelwood on a burnt brick stove. However, there are multiple constraints to cooking efficiency improvement, as indicated in paragraph 2.1.6.1.

4.3 Carbon forestry

4.3.1 Introduction

The first biomass energy supply system is based on carbon forestry. To initiate and execute a project like carbon forestry, institutional capacity is needed. It is assumed that a project developer is initiating a carbon forestry project on general land in East Shinyanga, since it is not likely that a local village government or a group of large land owners would initiate such a project on communal or private land. Furthermore, it is not likely that the Tanzanian government has funding available (UNFCCC 2007a). In general, such projects are executed by international or local project developers, e.g. NGOs or the World Bank. Host countries may initiate projects by writing a Project Idea Note (PIN), but they do not (yet) go through the whole project cycle of a CDM project (JIN 2008). The project developer has the option to sell tCERs or lCERs under the CDM, or VERs on the voluntary carbon market. In this analysis, these options are compared.

As indicated in paragraph 3.1.2, different quality standards exist for forestation projects on the voluntary carbon market. The higher the standards the better the integrity of the carbon credits can be secured. However, higher standards lead to higher transaction costs. To compare a project on the voluntary carbon market with a project under the CDM, I assume voluntary market standards that have more or less the same quality level as the CDM. This choice is morally based: More ‘dodgy’ carbon offset companies might be able to create more income for local communities, because of lower transaction costs, but this could lead to perverse incentives and false CO_2 mitigation. If a carbon sequestration project is undertaken, it should be done well, at least in a way that real carbon mitigation is guaranteed by a third party. Furthermore, ‘higher quality’ carbon credits bear a higher market price. Therefore, it is assumed that for the voluntary carbon market, general CDM guidelines are followed for this system.

To restore the natural value of the area, a monoculture forest is not preferable. A combination of tree species is planted that have the following characteristics (Rubanza 2007):

- Local species
- Low mortality rate
- Termite resistant
- Fire resistant
- Not attractive for cattle to demolish
- Local fuelwood and non-timber value like fodder, medicines, gum, bee-keeping, etc.

Appropriate species should be selected in accordance with local communities, since they can indicate best which species can facilitate local needs (Barrow 1996). Rubanza proposed the species *Acacia Polyacantha, Acacia Nilotica, Senna*

Siamea and *Azadiracta Indica* (Rubanza 2007), (See ICRAF Tree Database (ICRAF 2008). Trees are planted at the start of the wet season. Therefore, seedlings are raised in special nurseries 3-4 months in advance. To raise seedlings during the dry season, a water source is needed. At the start of the wet season, the raised seedlings are spotplanted and manure is applied. During spotplanting the vegetation is removed around the seedlings. The first three years, the forest is closed for cattle to avoid seedling destruction. Furthermore, to protect the seedlings against fires and to decrease competition for water and nutrients, the grasses are slashed twice per year during this period. It is important not to remove the vegetation completely because this will result in rainwater evaporation and runoff (Mshanga 2007). After these first three years, cattle can return to the forest for grazing and other benefits like leguminous fodder, medicines, bee-keeping, etc. can become available to the local community. In order to further reduce the risk of fires, fire lines are constructed and maintained. A wide spacing of trees is needed to create vegetation for cattle in the forest and this also avoids the need for thinning or pruning activities (Rubanza 2007).

Finally, the forest will become a sustainable source of fuelwood. Therefore, after the trees have reached a certain size, 10% of the annual biomass increment is reserved for fuelwood production, equal to the carbon forestry project in Tanzania as described in paragraph 3.1.1 (UNFCCC 2007a). Fuelwood is produced from pruning and selective felling and is collected by ox-cart to increase efficiency. However, fuelwood obtained from the forest should be deducted from the carbon stock and cannot be used for generating carbon credits, since the indirect benefit of avoided deforestation by providing a sustainable fuelwood supply is not eligible as a source of carbon credits under the CDM. A complete overview of the costs and benefits of this system are given in Figure 12. In this figure, costs and benefits both for the project developer and the local community are listed. Benefits that are not accounted for in this cost/benefit analysis, are pictured with a dotted line.

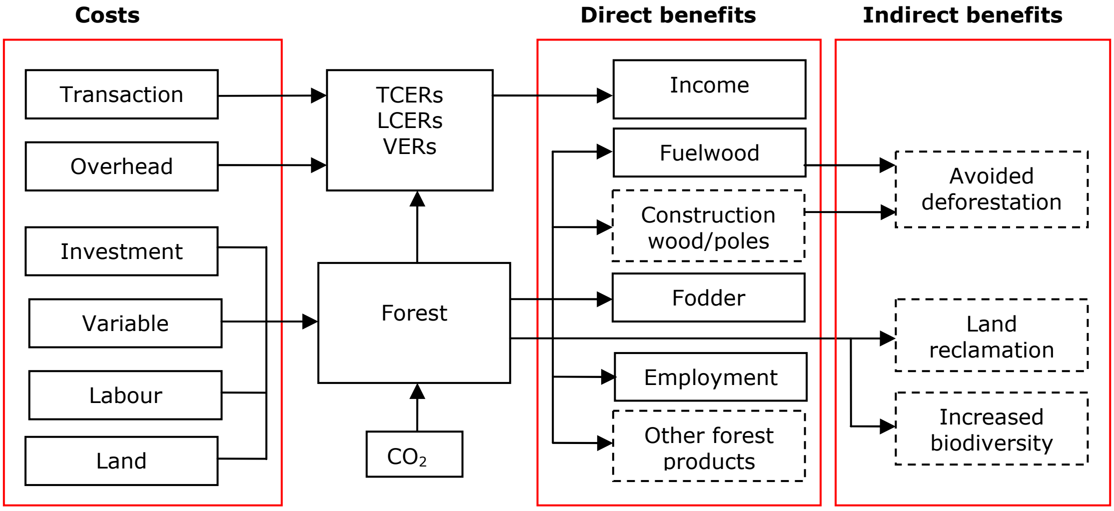

Figure 12: The costs and direct and indirect benefits of carbon forestry in semi-arid Shinyanga. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

Employment is created for the local population, so that the Return on labour consists of the minimum wage paid to the land workers, supplemented with the return on labour of collecting fuelwood. Indirect benefits are benefits related to land use change. Expressing these in a monetary value is beyond the scope of this research. 'Other forest products' indicate optional direct forest benefits like medicines, mushrooms, honey, etc. Again, the monetary value of these is considered to be beyond the scope if this research, because no useful data could be found. Construction wood and poles are needed for housing, tools, etc., but the average annual quantity of wood needed for this is not known, though it is considered to be rather insignificant compared to fuelwood consumption. Therefore, all these benefits are not accounted for in this cost/benefit analysis.

4.3.2 Methodology

4.3.2.1 Carbon credits

To determine the number of carbon credits that can be obtained, the annual mitigated CO_2 is calculated. As a guideline, an appropriate small-scale forestation methodology of the UNFCCC was applied. Monitoring, verification and issuance of carbon credits is carried out after each commitment period of 5 years (UNFCCC 2007b). The mitigated CO_2 after each commitment period is determined as follows:

$$M_{cp} = \sum_{t=n}^{t=n+5} B_t * (1+r) * A * 0.5 * 44/12 \qquad \text{(Formula 9)}$$

In which:
M_{cp} = CO_2 mitigated in commitment period (tonne)
B_t = the annual above-ground biomass increment (tonne dry matter/ha/year)
r = the root-to-shoot-ratio (dimensionless)
A = the forest area (ha)
0.5 = the carbon fraction of dry matter (tonne C/tonne dry matter)
44/12 = conversion factor from tonne C to tonne CO_2 (tonne C/tonne CO_2)

The increase in annual below-ground biomass increment relative to annual above-ground biomass increment is defined as the root-to-shoot-ratio. When applying this ratio, the total annual biomass increment is accounted for. Because the baseline situation consists of grasslands, the baseline carbon stock can be regarded as a constant and leakage because of indirect land use change can be assumed insignificant under small-scale methodology (UNFCCC 2007b).

As indicated before, only temporary carbon credits can be issued for forestation projects under the CDM. The project developer can thereby choose between so-called short-term CERs (tCERs) and long-term CERs (lCERs). tCERs are only valid during one commitment period and expire thus after five years. After the tCERs are expired, new tCERs can be issued for the same carbon stock. lCERs expire only after the end of the project crediting period, which is maximally 30 years. Both options are illustrated in Figure 13:

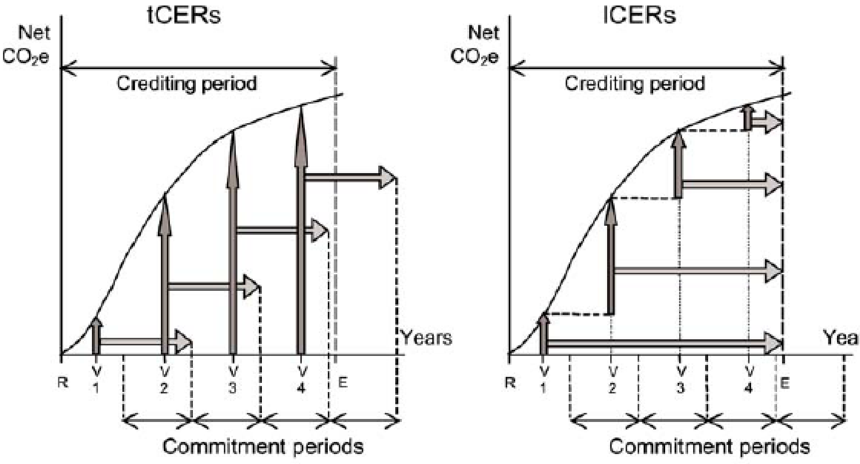

Figure 13: tCER issuance compared to lCER issuance after each commitment period. The horizontal arrows indicate the lifetime of the CERs, the vertical arrows indicate the quantity of CERs. Source: (Locatelli *et al.* 2006).

In this analysis, a crediting period of 30 years is assumed. The value of a temporary CER in relation to a permanent CER is determined by the following formula, which is following the logic that a credit buyer will only buy a temporary CER today and replace if by a permanent CER upon expiry, if that equals buying a permanent CER today (Neeff *et al.* 2007):

$$P_{\exp iringCER(0)} = P_{CER(0)} - \frac{P_{CER(t)}}{(1+d)^{ET}} \qquad \text{(Formula 10)}$$

In which:
$P_{\text{expiringCER}(0)}$ = The price of an expiring CER in year 0
$P_{\text{CER}(0)}$ = The price of a permanent CER in year 0
$P_{\text{CER}(t)}$ = The price of a permanent CER in year t
d = the real discount rate (of the credit buyer)
ET = expiring time of temporary credits

The total benefits of the carbon forest were calculated for both tCERs and lCERs, using formula 10. It is assumed that the CER market price is constant over the crediting period of the project. Furthermore, it is assumed that CERs are only sold to a credit buyer every 5 years, after each verification.

The Forests Absorbing Carbon Emissions (FACE) Foundation is a non-profit organization in the Netherlands that develops forest carbon sequestration projects for the voluntary market. FACE consults SGS Forestry as a third party for project verification, validation and certification (Snoep 2007). SGS is an officially approved consultancy for project verification and validation under the CDM, a so-called 'Designated Operational Entity' (DOE). SGS Forestry developed the QUALIFOR program for afforestation projects, which is accredited by the Forest Stewardship Council (FSC). QUALIFOR follows general CDM guidelines. However, since expiring credits can not be issued on a voluntary basis, the issue of the *permanence* of carbon sequestration is approached differently. The approach of SGS is to use a buffer: Permanent emission credits are issued for a certain percentage of the carbon stock. The rest of the stock is reserved as a buffer to assure permanence. The size of the buffer depends on the risk assessment, performed by SGS. In case of fires, pests, illegal logging, etc., this buffer can be used (SGS 2000). I followed this QUALIFOR permanence-guideline, since it is comparable to the expiring credits system under the CDM, in the sense that in both guidelines, total carbon stocks are regarded as non-permanent. Thus, the following quantity of VERs becomes available after each verification:

$$VER_{cp} = M_{cp} * (1-B) \qquad \text{(Formula 11)}$$

In which:
VER_{cp} = VERs available in commitment period
M_{cp} = CO_2 mitigated in the commitment period (tonne)
B = buffer size of forest (%)

The following transaction costs are relevant for small-scale CDM forestation projects (Cacho *et al.* 2007; Neeff *et al.* 2007):

• Project preparation	
• Project validation	
• Monitoring	(By local community, every five years)
• Verification	(By third party, every five years)
• Issuance fee	(Fee for the issuance of carbon credits: US$ 0,10/CER)
• Adaptation levy	(2% of produced CERs for CDM development fund)
• Bank fee	(In case of VER trade)

Monitoring of carbon stocks is executed by the local community, who have to be trained and equipped for this task. This does not only save costs, but also involves the local community in the carbon forestry project (Zahabu 2006).

4.3.2.2 Forestation costs

Forestation costs consist of investment, variable and labour costs. The following investment costs apply, using the capital recovery factor of formula 8:

$$C_{inv,pl} = \sum_{t=0}^{t=n} \alpha * \left((C_{seedling} + C_{manure}) * TD + C_{tool} \right) * A \qquad \text{(Formula 12)}$$

In which:
$C_{inv,pl}$ = Investment cost of planting the forest (US$)
$C_{seedling}$ = Cost of raising tree seedlings (US$/seedling)
C_{manure} = Cost of manure (US$/seedling)
C_{tool} = Cost of planting tools (US$/ha)
TD = the tree density (trees/ha)

First, tree seedlings have to be raised and planted. Furthermore, there are costs for equipment. These can be divided in fixed investment costs that are not depending on the forest size, specific investment costs that are dependent on the forest size and annual costs. These cost factors are based on a feasibility study of the RUVU Fuelwood Pilot Project (MNRT 1996), (See appendix B), since the carbon forestry project is comparable in organization and in equipment needed:

Investment costs (US$)	Specific investment costs (US$/ha)	Annual costs (US$/year)
Water supply for raising seedlings	Tractors for weeding, hauling, etc	Office expenses
Office renovation		Fuel
Office equipment		Operation & maintenance
Pick-up truck		

Table 15: Equipment costs of the carbon forestry project.

The number of tractors needed for weeding and fireline maintenance depends on the labour intensity (in man-hours/ha) of these activities by tractor. The total equipment costs can be determined as follows:

$$C_{equip} = \sum_{t=0}^{t=n} (\alpha * I_{fixed} + \alpha * I_{spec} * A + C_{annual}) \qquad \text{(Formula 13)}$$

In which:
C_{equip} = the total costs for equipment during the project (US$)
I_{fixed} = Fixed investment costs (US$)
I_{spec} = Specific investment costs (US$/ha)
C_{annual} = Annual costs (US$)

Field labour is needed for spotplanting, spotweeding, slashing and fireline maintenance. It is assumed that wages are paid to land workers, using the official minimum wage rate for land labour. In addition, there is educated labour: A project manager, a secretary and two foresters are assumed (MNRT 1996).

The cost of land consists of an annual land rent fee, which the project developer has to pay to the Tanzanian government for the title deed. Furthermore, the local community should be compensated for the first three years that the land is not available for grazing. I assumed that this compensation is equal to the land rent price for grazing land (see Table 6). To produce fodder, slashed grass is collected during these years. Afterwards, cattle is allowed in the woodland. For this analysis, I assumed no improvement in the fodder situation. This is a conservative estimate since pastoralists are likely to benefit from leguminous fodder sources that become available in the woodland.

The NPV of the total costs and benefits is determined as in formula 1. The costs and benefits of carbon forestry project are determined by the size of the forest. However, the size is constrained by the maximum annual CO_2 mitigation of 8 ktonne per year for small-scale projects under the CDM. On the voluntary market there is no constraint to the forest size.

As indicated before, after a number of years years, 10% of the annual biomass increment can be utilized for sustainable fuelwood production. The shadow cost of this wood energy is assumed to be equal to the opportunity of receiving carbon payment for the wood, plus the cost of harvesting the wood by ox-cart. This opportunity cost is determined in a similar fashion as formula 3:

$$COE_{cf} = \left(\frac{\sum_{t=0}^{n} \frac{B_{cc,t}}{(1+d)^t}}{\sum_{t=0}^{n} \frac{M_t}{(1+d)^t}} \right) * \frac{44/12 * 0.5 * BEF}{E_w} + C_{sh,harvest} \qquad \text{(Formula 14)}$$

In which:
COE_{cf} = The shadow cost of energy produced in a carbon forest (US$/GJ)
$B_{cc,t}$ = The benefit of selling carbon credit in year t (US$)
M_t = The mitigated CO_2 in year t
BEF = The Biomass Expansion Factor for converting woody above-ground biomass to total above-ground biomass (dimensionless) (UNFCCC 2007b)
$E_{LHV,wb}$= The energy content of air dry wood (GJ/tonne) (See section 4.2.3.3)
$C_{sh,harvest}$ = The shadow cost of labour for wood harvesting by ox-cart (US$/GJ)

4.4 Rotational woodlots

4.4.1 Introduction

The cost/benefit analysis of rotational woodlots is largely based on a study performed by Nyadzi *et al.* (HASHI 1998; Nyadzi *et al.* 2003). This study describes an experiment in which the performance of rotational woodlots in Shinyanga using *Acacia Polyacantha*, *Acacia Nilotica* and *Leucaena Leucocephala* tree species intercropped with maize, was measured over the period 1991-92 until 2000-01. The wood yield of *Acacia Polyacantha* and *Leucaena Leucocephala* was largely similar after seven years of growth, while *Acacia Nilotica* performed significantly less. *Leucaena Leucocephala* is a well-known fodder tree in Shinyanga, however, its success is hampered by the fact that it is rather susceptible to the leucaena psyllid, which feeds exclusively on *Leucaena Leucocephala* (HASHI 1998; Rubanza *et al.* 2006). Therefore, this analysis will be based on *Acacia Polyacantha*.

Acacia Polyacantha is a local, fast-growing, coppicing and termite resistant species that performs well in semi-arid Shinyanga and is locally preferred for fuelwood and timber, despite the fact that it is unpleasant to handle because of the exceptionally sharp thorns on the branches (Mbuya *et al.* 1994). Another disadvantage is that the wood produces low quality charcoal (Malimbwi 2007). *Acacia Polyacantha* is a ‘fertilizer tree’, which means that this species has a relatively high soil nitrogen fixing capacity. Intercropping is limited by the wide crown spread, which results in reduced maize yield after two years (HASHI 1996). Furthermore, *Acacia Polyacantha* produces gum and from the leaves and roots a medicine against snake bites can be obtained. At last, its roots are believed to have magical properties (ICRAF 2008). Fodder is produced by its pods, seeds and leaves (Mbuya *et al.* 1994).

In this analysis only the benefits of wood, fodder and intercropping are included. A farmer who established a woodlot has the option to produce fuelwood, charcoal or sell the tree stems as poles and only produce fuelwood or charcoal from the branches. Furthermore, the farmer can plant a monoculture, or practise intercropping. All configurations of these options will all be analysed. Furthermore, the impact of government taxes (see paragraph 2.1.6.1) on the produced wood will be analysed by calculating each configuration with and without tax. Figure 14 gives a complete overview of all the costs and benefits of this system:

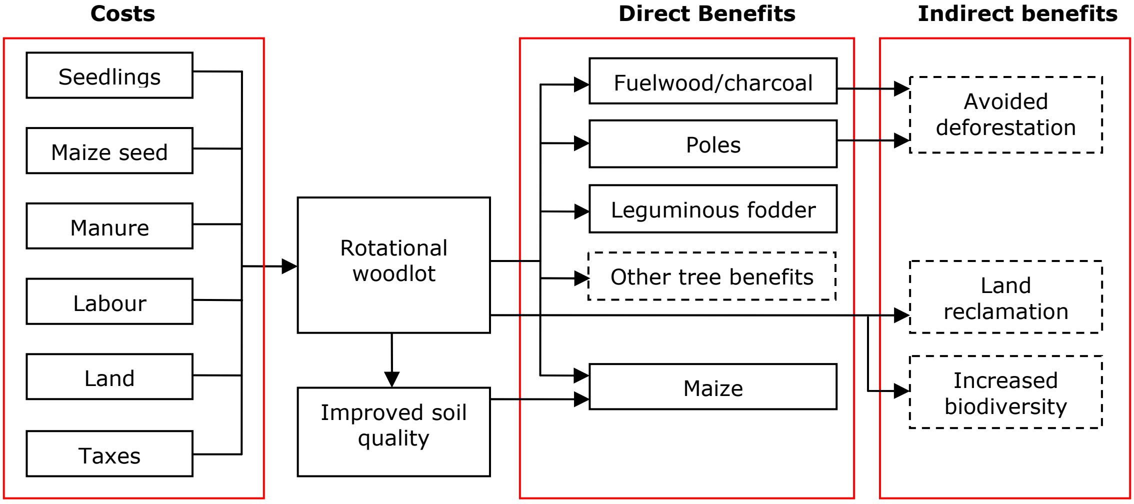

Figure 14: Costs and direct and indirect benefits of the rotational woodlot system. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

Improved soil quality is not listed as an indirect benefit here, since it directly influences maize production after the first tree harvest, when the soil quality is improved by the nitrogen fixing *Acacia Polyacantha* trees (Nyadzi *et al.* 2003). It is thus a direct part of the agroforestry system. Because of this difference compared to the baseline situation, the maize yields of intercropping are regarded as a benefit. Other tree benefits, like gum and medicines, are excluded from this cost/benefit analysis, because they are regarded to be insignificant.

The woodlot is established by a farmer on agricultural land, at the start of the rain season. It is assumed that commercial seedlings are available (Maganga 2007). Trees are harvested after seven years (Nyadzi *et al.* 2003). To create a constant annual wood supply, the woodlot area is divided in seven strata, of which one is planted with trees every year (see appendix E). In case of a monoculture woodlot, the trees are spotplanted and spotweeding and slashing is practised for 3 years, equal to the carbon forest. In year 4, the trees are large enough to allow cattle to graze. However, because of tree shading and water competition, vegetation fodder is less compared to fallow land (HASHI 1998). On the other side, tree pods are a protein-rich fodder source and leguminous fodder is produced when trees are harvested. Charcoal is produced using an improved earth kiln so that investment costs are avoided. Both fuelwood and charcoal can be used for household consumption or traded for cash. *Acacia Polyacantha* is a coppicing species so that new trees will emerge from coppices after harvesting (see Figure 8). It is assumed that these coppices will produce an equal amount of wood after 7 years, compared to the first rotation.

In case of intercropping, the land is tilted for maize production and trees are planted in between. Twice per growing season, the land needs to be weeded completely (Rubanza 2007). However, thereby spotweeding around trees and slashing is avoided. Maize cultivation is possible during the first 2 years of tree establishment. After this, tree shading and water competition cause maize harvests to decrease sharply so that intercropping is not economical anymore (Nyadzi *et al.* 2003). After the trees are cut, maize is planted in between the coppices, again for 2 subsequent years.

4.4.2 Methodology

4.4.2.1 Benefits of rotational woodlots

The rotational woodlot was analysed over a period of 3 rotations of 7 years each. This was decided because the costs of the first rotation are higher compared to subsequent rotations, since there are establishment costs for the woodlot. Furthermore, the maize yields will be higher in later rotations because of the soil fertility improvement, caused by growing *Acacia Polyacantha*. The total benefits were determined as follows:

$$B_{tot} = \sum_{t=0}^{t=21} B_t = \sum_{i=1}^{i=7} (Y_{wood(t),i} * P_{wood} + B_{leg(t),i} + B_{veg(t),i} + Y_{\text{int}(t),i} * P_{maize}) * A_i \qquad \text{(Formula 15)}$$

In which:
B_{tot} = The total benefits over the lifetime (US$)
B_t = The total benefits in year t (US$)
i = stratum i of woodlot area
$Y_{wood(t),i}$ = The wood yield in year t on stratum i (tonne dm/ha)
P_{wood} = The market price of wood (US$/tonne dm)
$B_{leg(t),i}$ = The benefits of leguminous fodder yield in year t on stratum i (tonne/ha)
$B_{veg(t),i}$ = The benefits of vegetation fodder in year t on stratum i (tonne/ha)
$Y_{int(t),i}$ = The maize yield of intercropping in year t, on stratum i (tonne/ha)
P_{maize} = The market price of maize (US$/tonne)
A_i = The size of stratum i (ha)

For the production of charcoal, the wood yield is multiplied by the kiln efficiency on a weight basis and the market price of wood is replaced by the market price of charcoal. In case of poles production, only the branches are converted to fuelwood and charcoal. Thus, a percentage of the yielded wood is sold for the market price of poles.

Only the benefit of leguminous fodder which is yielded when harvesting the trees, is included in this analysis. Tree pods and fruits falling down during the growing period of the trees is not included, because of a lack of information on the quantity and value of this fodder source. The benefit of leguminous fodder when harvesting the trees cannot be determined directly, since there appears to be no direct market value (see appendix D). Therefore, it is calculated by determining the value of vegetation fodder, based on the renting price of grazing land as determined in section 4.2.1. As a conservative estimate, the value of leguminous fodder is assumed to be equal to vegetation fodder. The total weight of leguminous fodder produced is determined by using the Biomass Expansion Factor for *Acacia Polyacantha*:

$$B_{leg} = \left(\frac{C_{grazing}}{V} \right) * Y_{wood} * (BEF - 1) \qquad \text{(Formula 16)}$$

In which:
B_{leg} = The benefit of leguminous fodder production (US$/ha)
$C_{grazing}$ = The land rent cost of grazing land (US$/ha/year) (see section 4.2.1)
V = the baseline annual vegetation growth (tonne dm/ha/year)
BEF = the Biomass Expansion Factor

In year 4, cattle is allowed in the woodlot for grazing. Though, because of tree shading, the vegetation growth in the woodlot will be less compared to plain grasslands (HASHI 1998). The benefits of vegetation fodder are determined in a similar way as in formula 16:

$$B_{veg} = \left(\frac{V_{wl}}{V} \right) * C_{grazing} \qquad \text{(Formula 17)}$$

In which:
V_{wl} = The average annual vegetation growth in the woodlot (tonne/ha)

4.4.2.2 Costs of rotational woodlots

The costs can be divided in investment costs (seedlings, manure and maize seed), annual labour costs, the opportunity cost of land and additional government fees in case of legal woodfuel trade (see Table 11). However, because tree planting is completed in 7 subsequent years on one stratum each year, the annual investment costs are relatively low. Labour (in man-days) is needed for the following activities:

Fuelwood production	Charcoal production	Maize intercropping
Planting of trees	Kiln preparation	Land preparation by hand hoe
Spotweeding	Carbonization	Maize sowing
Slashing	Unloading kiln	Manure application
Fireline maintenance		Weeding
Tree cutting		Harvesting
Wood shopping		Threshing

Table 16: Labour activities for fuelwood production, charcoal production and maize intercropping. When intercropping, spotweeding of trees and slashing is replaced by overall weeding and this activity is allocated to maize production.

It is assumed that labour for tree chopping is only needed for the percentage of the yielded wood that is used for woodfuel production. In case poles are produced from the tree stems, labour is saved on wood chopping.

When intercropping is practised, spotweeding of trees and slashing is replaced by overall field weeding, which is allocated to maize production, since without trees this activity would take place anyway. Furthermore, this is done to better determine the benefit of intercropping instead of establishing a monoculture woodlot. Another labour benefit of intercropping is the fact that tree planting is easier after land tilting for maize cultivation, compared to spotplanting in a monoculture woodlot.

For determining the opportunity cost of land in year t, it is assumed that in the baseline situation, the land would be cultivated with maize for two subsequent years, after which it would be left fallow for three years, as pictured in appendix F (Ramadhani *et al.* 2001). In years of cultivation, the opportunity cost of land in this system is equal to the renting price of agriculture and grazing land and in years of fallow, the opportunity cost is equal to only the renting price of grazing land (see section 4.4.1). The opportunity cost of land should be taken into account as a cost factor, because the NPV of the baseline maize-fallow system is defined as zero (see paragraph 4.2.2).

The extra costs and benefits of maize intercropping are regarded as additional costs and benefit and are thus not deducted from the opportunity costs of land. This is because the labour intensity of maize intercropping is less, compared to sole maize production and furthermore, the maize yields of intercropped maize are higher after the first tree rotation, because of the 'fertilizer effect' of the trees. Another reason is that in this way, the added value of intercropping can be more easily determined.

4.5 Jatropha oil production

4.5.1 Introduction

Two options are analyzed: A Jatropha plantation with intercropping on arable land that would have been used for agriculture in the absence of the project and a Jatropha monoculture plantation on degraded land that would have only been used for grazing in the absence of the project. Since little is known about Jatropha seed yields and since it is reported that Jatropha performs relatively well on marginal land, it is assumed that similar yields can be expected when the shrubs are nurtured well, especially during the first years of establishment. In case of agricultural land, Jatropha is intercropped during the first 5 years using understory crops, like groundnuts or beans, since these do not compete with Jatropha for light and water. After 5 years, the shading effect of the fast-growing Jatropha shrubs prevents further intercropping. To create spacing for intercropping, the Jatropha density has to be less compared to a monoculture (Mshanga 2007). The benefits of intercropping are expressed by the fact that the opportunity cost of agricultural land is zero when the land is intercropped and furthermore, slashing labour is allocated to crop production.

All the potential costs and benefits of this system are depicted in Figure 15. Seedlings are raised and transplanted at the start of the wet season. To maximize the number of branches (and fruits) on the shrub, a proper pruning scheme is important. Every four years the Jatropha shrubs are pruned. From the pruned stem, multiple coppices will emerge. To avoid competition, vegetation is removed by slashing and spotweeding around the shrubs. However, bare soil should be avoided since this increases water evaporation and runoff (Mshanga 2007). The costs and benefits of Jatropha oil production are illustrated in Figure 15:

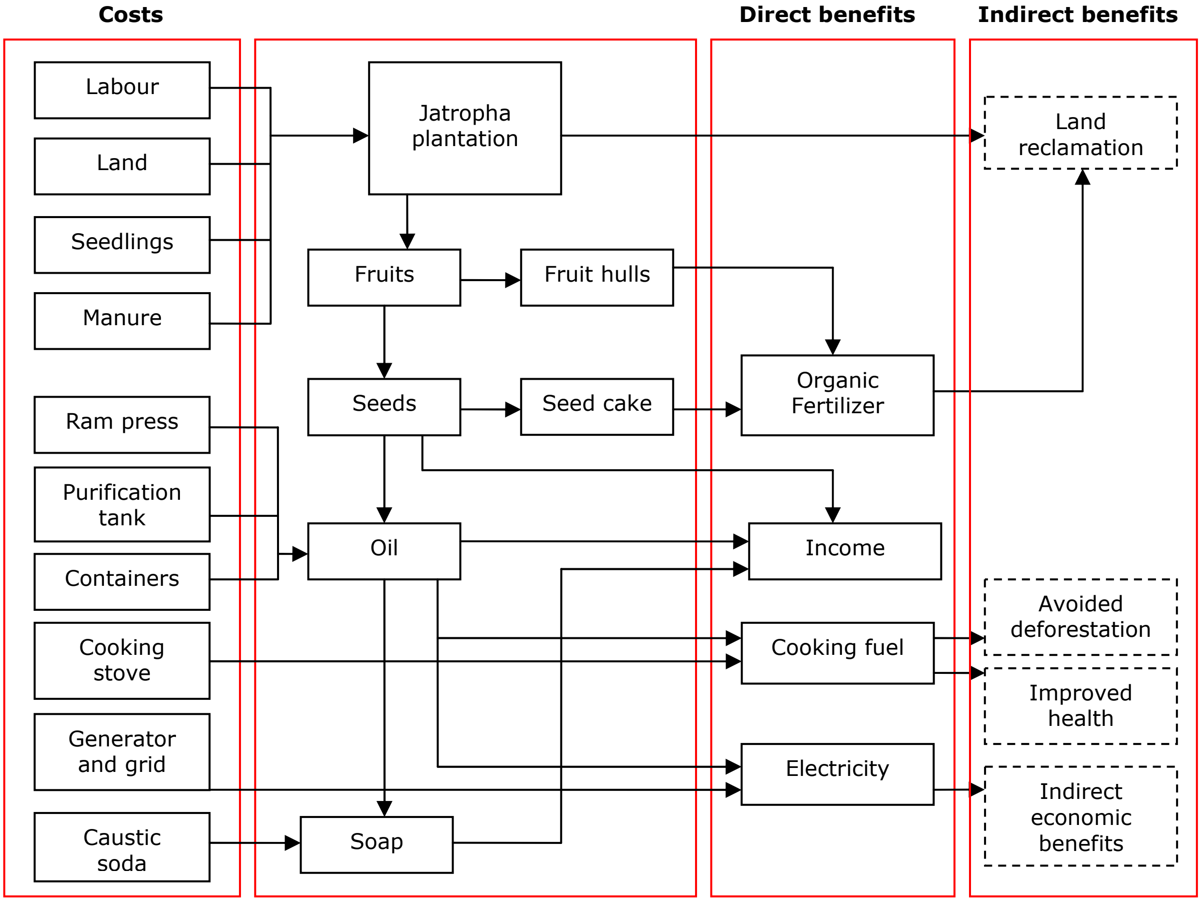

Figure 15: The potential costs and direct and indirect benefits of the Jatropha plantation. Benefits with a dotted line are not accounted for in the cost/benefit analysis.

The risk of fire is decreased by maintaining a fireline around the plantation. To allow fast growth, fertilizer is applied annually in the form of cattle manure and in case of oil production, in the form of seedcake. Hence, when oil is produced, seedcake replaces manure as a fertilizer. Irrigation is not practised.

The farmer has multiple options: Seeds can be directly sold to Diligent or alternatively, oil can be produced. Jatropha oil is produced by a manual ram press, after which it is filtered and temporary stored in vessels. It can be used for household cooking or for local electricity generation, using a generator. Alternatively, the oil can be used for the production of soap. Finally, the oil can be sold. Although there is no local market for Jatropha oil yet, in this analysis a local market for pure Jatropha oil as a blend in diesel engines is assumed. For comparative reasons, the lifetime of the plantation is assumed to be equal to the lifetime of the rotational woodlot, which is 21 years.

4.5.2 Methodology

4.5.2.1 Jatropha oil production

The total Jatropha oil production is determined as follows:

$$Y_{oil} = \sum_{t=1}^{t=21} \left(\frac{Y_{seed,t} * TD_J * A * F_{oil} * \eta_{press}}{D_J} \right) \qquad \text{(Formula 18)}$$

In which:
Y_{oil} = The total Jatropha oil production over the plantation lifetime (litre)
$Y_{seed,t}$ = The Jatropha seed yield in year t (kg/shrub)
TD_J = The Jatropha tree density (shrubs/ha)
A = The plantation area (ha)
F_{oil} = The fraction of oil in the Jatropha seeds
η_{press} = The ram press oil extraction efficiency
D_J = The density of Jatropha oil (kg/litre)

For Jatropha oil there is no market value yet. Assuming that the market price is equal to diesel or kerosene is likely to be too optimistic, since Jatropha oil cannot be directly used in conventional equipment. For this analysis, it is assumed that the local market value of Jatropha oil is equal to the value of diesel minus taxes (VAT, government levy on diesel and road toll) and minus the cost of transesterification to biodiesel. When Jatropha oil is used for cooking, the benefits are expressed in the avoided expenses on fuelwood:

$$B_{J,cooking} = \sum_{t=1}^{t=21} Y_{oil,t} * D_J * E_J * \eta_{stove,J} * \left(\frac{COE_{fw}}{\eta_{stove,fw}} \right) \qquad \text{(Formula 19)}$$

In which:
$B_{J,cooking}$ = The total benefit of cooking on Jatropha oil (US$)
$Y_{oil,t}$ = The Jatropha oil production in year t (litre)
E_J = The energy content of Jatropha oil (MJ/kg)
$\eta_{stove,J}$ = The efficiency of a Jatropha oil cooking stove
COE_{fw} = The Cost of Energy of fuelwood (US$/GJ)
$\eta_{stove,fw}$ = The average fuelwood stove efficiency in Shinyanga

4.5.2.2 Costs of Jatropha oil production

It is assumed that Jatropha seedlings are not available and have to be raised during the dry season. The production cost of Jatropha seedlings is assumed, based on the market price of tree seedlings. Raising seedlings involves significant investment costs. It is assumed that a loan is needed and that this loan is paid back over a period of 10 years, using a Capital Recovery Factor (see formula 8). Other costs involve manure application (in case seeds are sold and no seedcake is produced), labour and the opportunity cost of land:

$$C_{seed} = \sum_{t=0}^{t=21} (\alpha * I_{seedling} + M_{manure} * TD_{Jatropha} * P_{manure} + L_{seed,t} * W_{sh} + C_{land,t}) * A \qquad \text{(Formula 20)}$$

In which:
C_{seed} = The cost of Jatropha seed production (US$)
$I_{seedling}$ = The investment cost for seedlings in year 0 (US$/ha)
M_{manure} = The manure application in year t (kg/shrub)
P_{manure} = The price of manure (US$/kg)
$L_{seed,t}$ = Total labour intensity in year t (man-days/ha)
W_{sh} = The shadow cost of labour (US$/man-day)
$C_{land,t}$ = The opportunity cost of land in year t

Labour is needed for spotplanting, spotweeding, slashing, fireline maintenance, manure application, pruning, fruit harvesting and dehulling. Spotweeding is only needed during the first 3 years, after which the shading of the Jatropha shrub decreases vegetation growth and competition for water and nutrients is minimal (Mshanga 2007).

For the production of seeds, no fixed investment costs are needed so that the total costs and benefits increase linearly with an increasing plantation size. For Jatropha oil production however, a ram press and storage vessels have to be bought. Furthermore, there are extra labour costs for oil pressing and purification:

$$C_{oil} = C_{seed} + \sum_{t=0}^{t=21} (\alpha * I_{press} + I_{vessel,t} + L_{oil} * W_{sh} * Y_{oil,t}) \qquad \text{(Formula 21)}$$

In which:
C_{oil} = The costs of oil production (US$)
I_{press} = The investment cost of a ram press (US$)
I_{vessel} = The cost of oil storage vessels in year t (US$)
L_{oil} = The labour intensity of oil production (man-day/litre)

4.5.2.3 Jatropha oil for household cooking

The Cost of energy of Jatropha oil is determined as in formula 3. The total oil yield Y_{oil}, is expressed in GJ by multiplying with the energy content of Jatropha oil. In order to use the oil for household cooking, more investments are needed. There is no plant oil cooking stove on the market yet; however, it is assumed that the Bosch Siemens stove (see section 3.3) will be used. It is furthermore assumed that this stove requires annual maintenance. The cost of utilized heat of cooking on Jatropha oil can be determined similarly to formula 8:

$$COE_{h,Jatropha} = \frac{COE_{Jatropha}}{\eta_{stove,J}} + \frac{\alpha * I_{stove} + OM_{stove}}{E_{heat}} \qquad \text{(Formula 22)}$$

In which:
$COE_{h,Jatropha}$ = The cost of utilized heat when cooking on Jatropha oil (US$/GJ)
$COE_{Jatropha}$ = The cost of energy of Jatropha oil (US$/GJ)
$\eta_{stove,J}$ = The Jatropha oil stove efficiency
$I_{stove,J}$ = The cost of a Jatropha oil cooking stove (US$/HH)
OM_{stove} = The annual operation and maintenance costs of the stove (US$/HH/year)
E_{heat} = The annual household heat demand for cooking (GJ/HH/year)

Since the lifetime is different for various types of equipment, the capital recovery factor is calculated for each specific investment.

4.5.2.4 Jatropha oil for rural electrification

Another option is utilizing the annually produced Jatropha oil for electricity generation. Costs can be saved when replacing conventional diesel with Jatropha oil as a generator fuel for rural electrification. However, the generator has to be adapted to run on Jatropha oil. For calculating the cost of electricity, it is assumed that all the annual produced oil is used for electricity production. Furthermore, it is assumed that the electrification project is started when the annual Jatropha production is maximal, which is after 8-10 years of growth (Mshanga 2007). The number of households that can be connected to the small electricity grid depends on the household electricity demand. This also determines the capacity and cost of the generator. Furthermore, each household needs a power line, a socket and a light point. The number of households that can be connected is determined as follows:

$$N_{HH} = \frac{Y_{oil,\max} * \eta_{gen}}{D_{elec,HH}} \qquad \text{(Formula 23)}$$

In which:
N_{HH} = The number of households that can be connected
$Y_{oil,max}$ = The maximum annual oil production (GJ/year)
η_{gen} = The efficiency of the generator
$D_{elec,HH}$ = The annual household electricity demand (GJ/HH/year)

The cost of electricity is determined as:

$$COE_{elec,Jatropha} = \frac{\left(\alpha * \left(\left(P_{peak,HH} * C_{gen} + C_{grid,HH}\right) * N_{HH} + C_{adap}\right) + OM + Y_{oil,\max} * COE_{Jatropha}\right)}{(Y_{oil,\max} * \eta_{gen})} \qquad \text{(Formula 24)}$$

In which:
$COE_{elec,Jatropha}$ = The cost of electricity using Jatropha oil as a fuel (US$/GJ)/(US$/kWh)
$P_{peak,HH}$ = The household peak demand (W/HH)
C_{gen} = The cost of the generator (US$/W)
$C_{grid,HH}$ = The cost of a power line, socket and light point (US$/HH)
C_{adap} The cost of adapting the generator to run on Jatropha oil (US$)
OM = The annual operation and maintenance cost (US$/year)

4.5.2.6 Jatropha soap production

Using Jatropha oil for soap production instead of utilizing it for energy purposes might result in added value to the oil. Jatropha soap production is rather straightforward. One kg of soap is produced by boiling 0.5 litre oil, 0.5 litre water and 0.083 kg caustic soda (Henning 2003). Besides the cost of caustic soda, there are costs for labour, packaging and fuelwood for boiling. The soap can be sold to a transport company for a farm-gate price.

5. Input data

In this chapter the collected input data for this cost/benefit analysis is presented for each system. All costs and benefits were discounted using a real discount rate (corrected for inflation) of 11.8% (Bank of Tanzania 2008), (See Table 13).

5.1 Carbon Forestry

One of the most important input data needed for this system is the annual biomass increment of the woodland, in tonne dry matter per hectare. This is needed to determine the CO_2 mitigation per year. In order to do this most accurately, the annual biomass growth of the four selected tree species (see section 4.3.1) should be determined over the crediting period of the project. However, a serious lack of data on tree growth in semi-arid Shinyanga prevented such an approach. Some data could be obtained on biomass accumulation of tree species grown on agroforestry plots but only up to 7 years of growth (HASHI 1995; HASHI 1996; Nyadzi *et al.* 2003; Nyadzi *et al.* 2006). However, this is too limited to determine the growth over a period of 25 years. Therefore, I decided to estimate the annual growth increment more generally, based on the biomass stock of a mature forest in semi-arid conditions and the time needed for such a forest to become mature. However, an estimate of the biomass stock of Acacia woodlands in semi-arid Shinyanga could not be found. Therefore I adopted an estimate made by Mabugu *et al*., who indicated a default biomass stock of 50 tonne dm/ha for mature dry woodlands in Zimbabwe (Mabugu *et al.* 2002). I assumed that the woodland will grow for 25 years, which leads to a mean annual above-ground biomass increment (MAI) of 2 tonne dm/ha/year. In reality the forest will follow a logistic growth pattern. However, because of a lack of data, I will use the MAI for this analysis. A MAI of 2 tonne dm/ha/year and a maximum above-ground biomass stock of 50 tonne dm/ha were confirmed by Malimbwi to be reasonable estimates (Malimbwi 2007), who determined an equal MAI for Miombo woodlands in Tanzania (Malimbwi *et al.* 2007). The impact of the MAI on the NPV of the project is measured in the sensitivity analysis.

The data on equipment costs are mostly taken from the cost estimate of the Ruvu Fuelwood Pilot Project, a farmer-managed woodfuel production forest, close to Dar es Salaam (MNRT 1996) (See appendix B). Labour intensity is mostly based on information provided by Rubanza and Maganga (2007). The input data for the carbon forestry system is listed below:

Parameter	**Data**	**Unit**	**Source**	**Remarks**
WOODLAND GROWTH				
MAI	2	Tonne dm/ha/year	Estimate	See above
Maximum biomass stock	50	Tonne dm/ha	(Mabugu *et al.* 2002)	See above
Root-to-shoot-ratio	0.40		(IPCC 2006)	For tropical shrubland
Fuelwood production	10%			Of MAI
First year of yield	7	Year	Estimate	From year 7 there is an annual wood harvest
CARBON CREDITS				
CER price	16,55	Euro	www.carbonpositive.net	Secondary market price 25-03-2008
Crediting period	30	Years		
Credit buyer discount rate	4.75%		www.carbonpositive.net	See below[2]
CDM TRANSACTION COSTS				

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[2] Determined indirectly: CER price 07-2007 = €14,50, tCER price 07-2007 = €3,00 (Carbonpositive.net). Input in formula 10, using a crediting period of 5 years, yields a discount rate of 4.75%.

Project development	30.000	US$	Estimate	In year 0. Based on (World Bank 2003; Locatelli *et al.* 2006; Cacho *et al.* 2007)
Validation	25.000	US$	(SGS 2007)	In year 0
Monitoring	8.081	€$_{2006}$	(Zahabu 2006)	In year 5
	5.040	€$_{2006}$	(Zahabu 2006)	In year 10, 15, 20, 25
Verification first monitoring	15.000	US$	(SGS 2007)	In year 5
Verification next	7.500	US$	(SGS 2007)	In year 10, 15, 20, 25
CER issuance fee	0,10	US$/CER	(Neeff *et al.* 2007)	
Adaptation levy	2%	Of CERs	(Neeff *et al.* 2007)	
VOLUNTARY MARKET[3]				
VER price	10	€	(Snoep 2007)	
Forest buffer size	25%		(SGS 2000)	For risk mitigation
Project development	25.000	US$	Estimate	See below[4]
Bank fee	2.5%	Of turnover	(Snoep 2007)	Triodos Climate Clearing House fee
FORESTATION COSTS				
Land lease registration	220.500	Tsh	www.doingbusiness.org	Tanzania page
Annual land lease fee	500	Tsh/acre/yr	(TRA 2008)	
Tree density	400	Trees/ha	(Rubanza 2007)	Spacing 5 x 5 meter
Cost of seedlings	60	Tsh$_{1996}$/piece	(MNRT 1996)	
Cost of planting tools	5.682	Tsh$_{1996}$/ha	(MNRT 1996)	Converted for tree spacing of 3 x 3 m. at Ruvu project.
Manure application	2.5	Kg/seedling	(Rubanza 2007)	Only for planting
Price of manure	1969	Tsh/tonne	Estimate	See below[5]
LABOUR COSTS				
Spotplanting	12	minutes/tree	(Maganga 2007)	See below[6]
Spotweeding	3	Minutes/tree	Estimate	2 x per year, only in year 1 – 3 (Rubanza 2007).
Slashing using tractor	0.5	Man-days/ha	Estimate	2 x per year, only in year 1 – 3 (Rubanza 2007).
Fireline maintenance using tractor	0.5	man-days/ha/year	Estimate	
Wage rate	80.000	Tsh/month	(Morogoro 2007)	
Project manager	600.000	Tsh/month	Estimate	
Secretary	200.000	Tsh/month	(Mwamhanga 2007)	
Forester	300.000	Tsh/month	(Mwamhanga 2007)	2 foresters are estimated
Non-wage labour cost	16%		www.doingbusiness.org	Tanzania page
Fuelwood collecting	20	Headloads/ man-day	Estimate	Using an ox-cart. 20 headloads = 1 ox-cart
EQUIPMENT COSTS				
Water supply	6.000.000	Tsh$_{1996}$	(MNRT 1996)	
Pick-up truck	20.000.000	Tsh$_{1996}$	(MNRT 1996)	One truck assumed
Office renovation	5.000.000	Tsh$_{1996}$	(MNRT 1996)	
Office equipment	2.400.000	Tsh$_{1996}$	(MNRT 1996)	
Tractor and harrow	25.000.00			See below[7]
Lifetime equipment	30	Years	Assumption	
O&M tractors and truck	3%	Per year	Assumption	Of investment cost
Office expenses	3.000.000	Tsh$_{1996}$/year	(MNRT 1996)	
Diesel cost	1.500	Tsh/litre		In Shinyanga urban
Diesel cost slashing	6.000	Tsh/ha	Estimate	Based on assumed efficiency of 1 litre/km
Diesel cost Fireline	600	Tsh/ha	Estimate	
OVERHEAD COSTS				
Overhead costs project	13%	Of all costs	(Bretton Woods 2008)	World Bank Carbon Fund

Table 17: Input data for cost/benefit analysis of carbon forestry in semi-arid Shinyanga.

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[3] Validation, monitoring and verification costs are equal to CDM costs.

[4] The Project Design Document (PDD) does not have to be according to CDM standards. Furthermore, time is saved because the CDM procedure is rather time consuming (Snoep 2007).

[5] Average of prices mentioned in the survey (see appendix C) and by Bakengesa (12.500 Tsh$_{2007}$/ox-cart), (Bakengesa 2007), using a weight of 0.35 tonne manure per ox-cart (Rubana 2007)

[6] Labour cost is 15.000 Tsh/acre, divided by assumed shadow labour cost of US$1,43 per man-day.

[7] The number of tractors needed depends on the woodland size. The labour intensity for slashing by tractor is estimated to be 1 man-day/ha/year and for fireline maintenance 0.5 man-days/ha/year.

5.2 Rotational woodlots

This analysis is largely based on a rotational woodlot study in Shinyanga (Nyadzi *et al.* 2003). Both the measured wood yields as the maize intercropping yields of this study were used. The labour intensities of maize production activities are averages of the studies used for determining the baseline shadow cost of labour (see appendix D). The labour intensity of charcoal production is based on Malimbwi *et al.* (2007). The following input data was used for the cost/benefit analysis of the rotational woodlot:

Parameter	**Data**	**Unit**	**Source**	**Remarks**
BIOMASS PRODUCTION				
Rotation period	7	Years	(Nyadzi *et al.* 2003)	
strata	7			One planted per year
Project lifetime	21	Years		3 rotations first stratum
Wood harvest	70.9	Tonne dm/ha	(Nyadzi *et al.* 2003)	
Tree density	833	Trees/ha	(Nyadzi *et al.* 2003)	Spacing 3 x 4 meter
Energy content *Acacia Polyacantha*	19.8	MJ/kg oven dry wood	Assumption	Assumed to be equal to *Acacia Nilotica* (see section 4.2.3.3)
Wood density *Acacia Polyacantha*	0.78	Tonne dm/m^3	(ICRAF 2008)	0.72 – 0.84 tonne/m^3
Biomass Expansion Factor	1.23	Tonne dm total biomass/tonne dm wood	(HASHI 1995)	For 6 year old *Acacia Polyacantha*
Vegetation growth in woodlot	40%	of normal growth	(HASHI 1998)	*Acacia Polyacantha* in year 4.
Baseline annual vegetation growth	2	Tonne dm/ha/year	(Rubanza 2007)	1.5 – 2.5 tonne dm/ha/year
Charcoal kiln efficiency[8]	30%	Weight basis	(Malimbwi 2007)	Best practise
Stem wood for poles	40%	Of total wood	Estimate	
Price of poles	39	US$/tonne wood	Survey appendix C and (MNRT 1996)	See below[9]
GOVERNMENT TAXES				
Government registration fee woodfuel production	200.000	Tsh/year	(Maganga 2007)	Also when produced from private land.
Payable fee fuelwood	4.000	Tsh/ox-cart	(Maganga 2007)	Counted as 1 m^3.
Payable fee charcoal	2.000	Tsh/bag	(Maganga 2007)	
Local district fee charcoal	200	Tsh/bag	(Maganga 2007)	
Payable fee poles	2.000	Tsh/pole	(Maganga 2007)	With Ø > 0.10 meter.
Reduction payable fees for woodlots	80%		(Maganga 2007)	When produced from private land
PLANTING COSTS				
Price of seedlings	150	Tsh/seedling	(Maganga 2007)	100 – 200 Tsh/seedling
Manure application	2.5	Kg/seedling	(Rubanza 2007)	Only for planting
LABOUR INTENSITY[10]				
Tree planting tilted land	88	Trees/man-day	(Ramadhani *et al.* 2001)	Land is already tilted for maize cultivation.
Slashing by hand	8	Man-days/ha	(MNRT 1996)	2 x per year, only in year 1 – 3 (Rubanza 2007).
Fireline maintenance	10	Man-days/ha	(MNRT 1996)	Each year by hand
Tree cutting	0.38	Man-days/tonne	(Ramadhani *et al.* 2001)	Dry matter wood
Wood chopping	1.46	Man-days/tonne	See below[11]	Dry matter wood
Kiln preparation	6.7	Man-days/tonne charcoal	(Malimbwi *et al.* 2007)	

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[8] Other charcoal input data is listed in Table 11.

[9] Average of Tsh_{2007} 2.000 for pole 3 x Ø0.15 meter (= $US\$_{2007}$ 40,18/tonne wood), (See appendix D) and Tsh_{1996} 18.000 /m^3 for poles (= $US\$_{2007}$ 37,40/tonne wood) (MNRT 1996).

[10] For monoculture woodlots, spotplanting and spotweeding labour intensity is assumed to be equal to carbon forestry.

[11] Average of 1.28 man-days/tonne wood (Ramadhani *et al.* 2001) and 1.65 man-days/tonne wood. The latter is based on 13 man-days per 1.5 tonne charcoal at a kiln efficiency of 19% (Average in Tanzania) (Malimbwi *et al.* 2007).

Carbonization	9.3	Man-days/tonne charcoal	(Malimbwi *et al.* 2007)	
Unloading kiln	2.7	Man-days/tonne charcoal	(Malimbwi *et al.* 2007)	
INTERCROPPING				
Land preparation by hand hoe	27.5	Man-days/ha	See appendix E	Average of studies
Maize sowing	3.8	Man-days/ha	See appendix E	Average of studies
Weeding	20.7	Man-days/ha	See appendix E	Average of studies
Manure application	2	Man-days/ha	Estimate	Based on (Ramadhani *et al.* 2001)
Harvesting and threshing	15.8	Man-days/ha	See appendix E	Average of studies
Price of maize seed	2.500	Tsh$_{1998}$/ha	(Van der Linde *et al.* 1998 in Limbu 1999)	
Manure application	5	Tonne/ha/year	Assumption	0.5 kg/m^2
Maize yield start, year 1	100%	Of baseline yield	Estimate	Based on (Nyadzi *et al.* 2003)
Maize yield start, year 2	70%	〃	〃	〃
Maize yield after tree harvest, year 1	200%	〃	〃	〃
Maize yield after tree harvest, year 2	125%	〃	〃	〃

Table 18: Input data for cost/benefit analysis of rotational woodlots in semi-arid Shinyanga.

5.3 Jatropha oil production

An important parameter is the Jatropha seed yield in semi-arid Shinyanga, however this parameter is also rather uncertain, since seed yields in Shinyanga have never been measured. Henning reports seed yields of 2.8 tonne/ha/year in Mali (Henning 2003). Mshanga indicates a first yield of 0.5 to 1 kg/shrub in year 3-4 and a maximum yield of 4 kg/shrub in year 8-10. However, this estimate is based on agricultural land in Arusha. In semi-arid Shinyanga and on marginal land, the yield will be lower (Mshanga 2007). Van Eijck estimates a maximum yield of 1.5–2 kg/shrub in Shinyanga, after four years of growth and under good management (van Eijck 2007a). Furthermore, yields depend on the pruning scheme. Intensive pruning, as advocated by Mshanga, will delay, but also increase the maximum yield, since the shrub will develop more branches (Mshanga 2007). Based on this, I estimated an annual seed production per shrub of 0.5 kg in year 3, 1.0 kg in year 4 and 5, 1.5 kg in year 6–8 and a maximum of 2.0 kg in year 9 and onwards. For reasons given in the previous chapters, the seed yield is assumed to be equal for cultivation on arable land and on marginal land. The impact of the seed yield on the economic feasibility of Jatropha cultivation will be examined by means of a sensitivity analysis. There is a lack of data on the labour intensity of smallholder Jatropha cultivation. Therefore, it is assumed that the labour intensity of (spot)planting, slashing and Fireline maintenance is equal to rotational woodlots. The labour intensity of seed picking and oil production is based on Henning (2004) and van Eijck (2007). Data on electrification is mainly based on information provided by TANESCO and data on soap production originates from Henning (2003) and Matchmaker (2007). Further, input data for this analysis is listed below:

Parameter	Data	Unit	Source	Remarks
JATROPHA OIL PRODUCTION				
Project lifetime	21	years		
Shrub density monoculture	1600	Shrubs/ha	(Mshanga 2007)	Spacing 2.5 x 2.5 meter
Shrub density intercropping	1333	Shrubs/ha	(Mshanga 2007; (Henning 2003)	Spacing 2.5 x 3 meter
Intercropping years	5	Years	(Mshanga 2007)	From establishment
Pruning years	4,8,12,..		(Mshanga 2007)	Every 4 years
Annual manure application	1	Kg/shrub/year	(Mshanga 2007)	When seedcake is not

				available for fertilization
Seedcake/cow manure equivalent	3.9	Kg manure/ kg seedcake	(van Eijck 2007b)	Based on N-rate
Seed weight	46%	Of total fruit	(Openshaw 2000)	
Oil content Jatropha seeds	38%		(Pant *et al.* 2006)	On higher altitude
Oil extraction rate ram press	62.5%		(Henning 2003)	60 – 65%
Jatropha oil density	0.92	Kg/litre	(Openshaw 2000)	
Jatropha oil energy content	40.7	MJ/kg LHV	(Openshaw 2000)	
PRODUCTION COSTS				
Farm-gate price seeds	100	Tsh/kg	(van Eijck 2007a)	For Diligent, when produced in Shinyanga
Cost of raising seedlings	100	Tsh/seedling	Estimate	See below[12]
Pay-back period seedlings	10	years	Assumption	Using capital recovery factor
Diesel price	1.800	Tsh/litre	See appendix D	In rural Shinyanga
Government levy	200	Tsh/litre	(TRA 2008)	
Road toll	100	Tsh/litre	(Tanzania 2006)	
Value Added Tax (VAT)	20%		(TRA 2008)	
Transesterification cost	0,25	US$/litre	Assumption	Including transport
Cost of ram press	220.000	Tsh	(Mshanga 2007)	
Lifetime of ram press	5	Years	(Henning 2003)	
Cost of vessel	15.000	Tsh		250 litre
Cost of Jatropha oil cooking stove	40	Euro	(Kratzeisen *et al.* 2007)	
Efficiency Jatropha oil stove	45%		(BHS 2008)	40 – 50%
Lifetime Jatropha oil stove	5	Years	Estimate	
LABOUR INTENSITY[13]				
Pruning	2	Minutes/shrub	Estimate	
Manure application	2	Man-days/ha	Estimate	
Seed harvesting	40	Man-day/tonne seed	See below[14]	
Oil pressing and filtering	1.5	hour/litre oil	(Henning 2004)	
ELECTRICITY PRODUCTION				
Cost of generator	184	US$/kW		Based on average of shop prices in Morogoro.
Generator efficiency	27%		(Ilskog *et al.* 2005)	
Cost of generator adaptation for Jatropha oil	1.000.000	Tsh/engine	(Van Eijck 2007)	
Primary electricity cable	11.181	Tsh/meter	(Semsella 2007)	
Electricity cable length	10	Meter/HH	Assumption	Length needed per house
Secondary cable, installation and meter	246.000	Tsh/HH	(Semsella 2007)	Assumed to be equal to TANESCO rate
Light point	9.125	Tsh/HH	(Semsella 2007)	
Socket	13.960	Tsh/HH	(Semsella 2007)	
CFL lamp, 15 W	7.000	Tsh/HH	(Semsella 2007)	
Electricity demand	35	kWh/HH/month	(Ilskog *et al.* 2005)	
Peak demand	1000	W/HH	Assumption	Cooking or machine operation
Annual O&M	4%	Of investments	Assumption	
Lifetime investments	10	Years	Assumption	
SOAP PRODUCTION				
Weight of soap per piece	90	Gram	(Matchmaker 2007)	
Selling price soap farm-gate	500	Tsh/piece	(Matchmaker 2007)	
Jatropha oil needed	0.56	Litre/kg soap	(Henning 2003)	
Caustic soda needed	0.093	Kg/kg soap	(Henning 2003)	
Cost of caustic soda	700	Tsh/kg	(Matchmaker 2007)	
Labour intensity soap making	0.74	Man-hour/kg	(Henning 2003)	
Energy cost	300	Tsh/litre Jatropha oil	(Matchmaker 2007)	
Packaging	160	Tsh/kg soap	(Henning 2003)	

Table 19: Input data for cost/benefit analysis of Jatropha oil production in semi-arid Shinyanga.

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[12] Based on the market price of 100 – 200 Tsh/seedling for acacia seedlings (Maganga 2007).

[13] Labour intensity of planting, slashing and fireline maintenance in both the monoculture or intercropping system, is assumed to be equal to the rotational woodlot system.

[14] Based on (Henning 2004): 3 kg seed/hour, which is 41.7 man-days/tonne, and (Van Eijck 2007b): 33 – 40 man/days/tonne seed.

6. Results

In this chapter the results of this cost/benefit analysis are presented. First, the results of the individual systems are presented, including a sensitivity analysis on the main parameters and followed by a short discussion. Next, the results of the systems are compared and discussed.

6.1 Carbon Forestry

6.1.1 Results of the cost/benefit analysis

The project developer has the option to sell tCERs, lCERs or VERs. Under the CDM, a cap of 8 ktonne CO_2 per year for small-scale projects applies, while on the voluntary market there is no such constraint. To mitigate this amount of CO_2 annually, 1558 ha of woodland would be needed. The NPV of the net benefits of trading different carbon credits at an annual CO_2 mitigation of 8 ktonne is presented below. The net benefit is defined as the benefits of trading carbon credits, minus the transaction costs. Permanent carbon credits cannot be obtained for forestry projects. However, to illustrate the difference in benefits between permanent and temporary credits, the supposed CER benefit is listed:

NPV (US$)	**supposed**	**Forestation carbon credits**		
	CER	**TCER**	**LCER**	**VER**
NPV transaction costs	79.741	79.741	79.741	72.486
NPV carbon credit income	1.065.182	464.953	625.727	480.814
NPV net benefit	985.441	385.212	545.986	408.328
NPV net benefit relative to permanent CERs	100%	39.1%	55.4%	41.4%

Table 20: NPV of net benefits of different types of forestation carbon credits at an annual CO_2 mitigation of 8 ktonne. The supposed CER benefit is listed for comparison.

Table 20 shows that the temporary credit system significantly reduces the value of forestation carbon credits, compared to conventional CERs. Selling lCERs is the most attractive option, which is mainly caused by the fact that at the first CER issuance after five years, the value of an lCER is still relatively high, since it will be valid for 25 years. The benefits of VERs are significantly reduced by the buffer size. The overall Net Present Value, Return on Labour and Cost of Energy of the carbon forestry project, when trading lCERs, is listed below:

Parameter	**Value**	**Unit**
Land size needed	1558	ha
Overall Net Present Value	-407.311	US$
	-261,36	US$/ha
Return on Labour land worker	3,80	US$/man-day
Cost of fuelwood harvesting	0,28	US$/GJ
Carbon cost of energy project developer	1,18	US$/GJ
Total cost of energy project developer	1,40	US$/GJ

Table 21: Main results of the cost/benefit analysis of carbon forestry in semi-arid Shinyanga, at an annual CO_2 mitigation of 8 ktonne and when trading lCERs.

The results show a significantly negative overall NPV over the whole project. The main reason is the relatively low MAI of 2 tonne dm/ha. To mitigate 8 ktonne of CO_2 annually, significant land area is needed. This causes high labour and specific investment costs. The Return on labour for the local community is the official minimum wage earned for land work plus the benefit of fuelwood collecting, which is higher as the reference Return on labour for maize production of US$

1,88 per man-day. The carbon cost of energy indicates the cost of wood when expressed in its carbon value (see formula 14) and consists of the benefits foregone for the project developer, when reserving 10% of the annual biomass increment for fuelwood production. This value is lower as the market price of fuelwood (US$ 1,95 per GJ), which confirms the hypothesis that a carbon forestation project on smallholder land would not be realistic, since the value of wood in terms of energy is much higher as the carbon value. Furthermore, smallholder farmers would at most receive a part of the benefits from the trade in carbon credits.

The total cost of energy in Table 21 indicates the difference in total NPV between a project with and without 10% of the biomass increment reserved for fuelwood. Again, this is the cost of energy for the project developer, not for the local community.

The cost of energy for a community consists of the shadow cost of labour of harvesting the fuelwood, which is estimated to be US$ 0,28 per GJ, when collected by ox-cart. In case of 10% fuelwood harvesting, 312 tonne of wood can be harvested from the forest each year, after seven years of growth. This is enough to cover the demand of about 39 households, based on a per capita fuelwood demand of 1.20 tonne dm/cap/year (see Table 9). When assuming a fuelwood market price of Tsh 600 per headload, the total NPV of this fuelwood benefit over the lifetime of the project is US$ 27.868, or US$ 17,88 per ha. Assumed that the local community can chose between harvesting fuelwood, or receiving the carbon value of 10% of the MAI by other means, the total opportunity cost of fuelwood becomes the carbon value of the wood plus the shadow cost of harvesting, which totals to US$ 1,46 per tonne dry matter. The NPV of the total costs of the carbon forestry project are broken down in Figure 16:

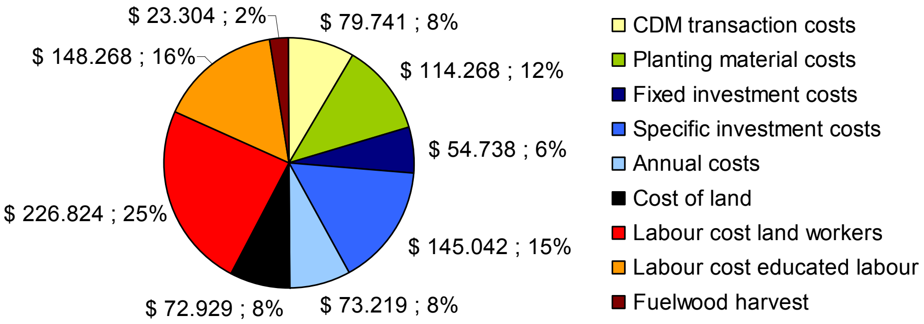

Figure 16: Breakdown of the NPV of the costs of carbon forestry in semi-arid Shinyanga at a woodland size of 1558 ha, from the perspective of the project developer/investor.

Transaction costs account for only 9%, while labour costs cover 41% of the total costs. The large share of educated labour, which is only 4 fte, is caused by the relatively large income difference in a developing country like Tanzania. The large land area needed leads to relatively high land labour costs and specific investment costs, which are mainly the costs of tractors needed for slashing and fireline maintenance. Land labour is foremost needed in the first years of the project establishment. Planting provides 93 fte of labour in year 0. Slashing and fireline maintenance provides 56 fte in year 1–3, but only 3 fte from year 4 and onwards. The cost of fuelwood harvest is defined as the difference in total NPV between the project with and without 10% fuelwood harvest. It accounts for only 2% of the NPV of the costs.

6.1.2 Sensitivity analysis

The impact of the most important and uncertain parameters on the outcome of this cost/benefit analysis was determined by means of a sensitivity analysis. These parameters are woodland size, MAI, carbon credit price and the discount rate.

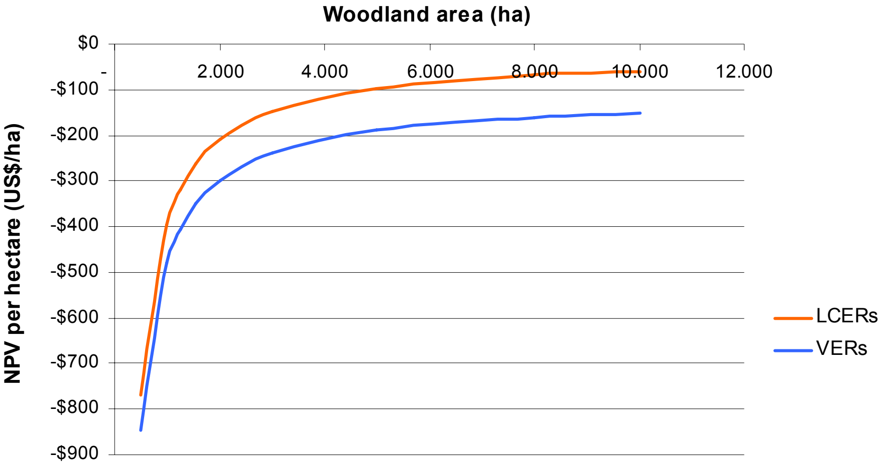

Figure 17: NPV per hectare of carbon forestry as a function of the woodland area, for both lCERs under the CDM and VERs on the voluntary market.

Figure 17 illustrates that carbon forestry is not economically feasible in the semi-arid conditions of Shinyanga, not under the CDM, nor via the voluntary market. At an increasing woodland size, the costs increase more rapidly as the benefits. The impact of the MAI on the economic feasibility of carbon forestry, when trading lCERs and when mitigating 8 ktonne CO_2 annually, is presented in Figure 18:

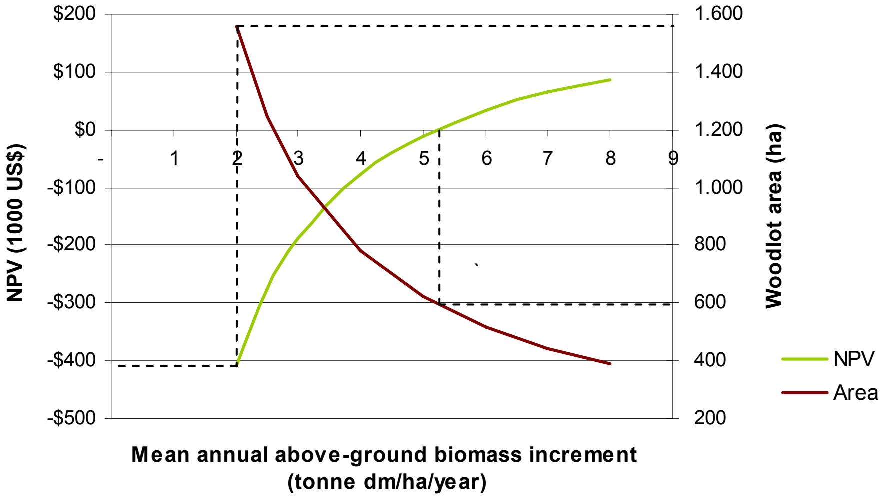

Figure 18: Left Y-axis: NPV of carbon forestry as a function of the MAI, when trading lCERs and when mitigating 8 ktonne of CO_2 annually. Right Y-axis: Area needed to mitigate 8 ktonne of CO_2. The left dashed line indicates the situation as estimated. The right dashed line indicates the MAI needed for a breakeven NPV.

The NPV is rather sensitive to the MAI, but only at a mean increment of 5.2 tonne dm/ha/year, a breakeven between costs and benefits is reached when applying small-scale forestation under the CDM. At such an increment the forest size is reduced to 597 ha. A MAI of 5.2 tonne dm/ha/year is not realistic in dry forests, which make up 90% of all the forests in Tanzania (Malimbwi *et al.* 2000; Chitiki *et al.* 2007).

Figure 19 pictures the area needed to reach a breakeven NPV and the related annual CO_2 mitigation as a function of the MAI, when trading VERs:

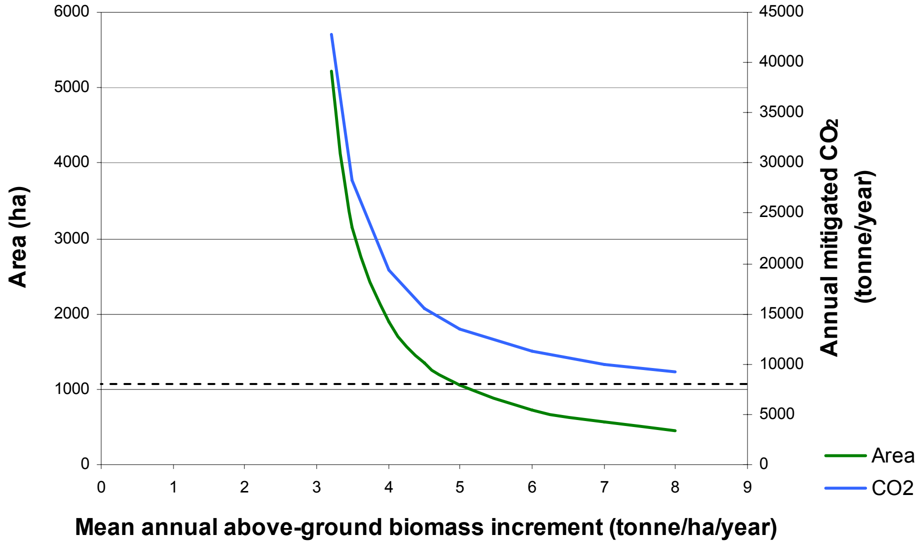

Figure 19: Forest area needed and mitigated CO_2 at an NPV of 0, as a function of the MAI, when trading VERs on the voluntary market (left axis) and annual mitigated CO_2 (right axis). The dashed line indicates the CDM cap of 8 ktonne CO_2 per year.

Since VER trade is not constraint by a cap on the annual mitigated CO_2, the breakeven NPV can be reached at a lower MAI as the CDM, but at a larger forest size. A breakeven NPV is only possible at an annual CO_2 mitigation of more than 8 ktonne. Figure 20 shows the NPV of the carbon forestry project under the CDM as a function of the CER market price:

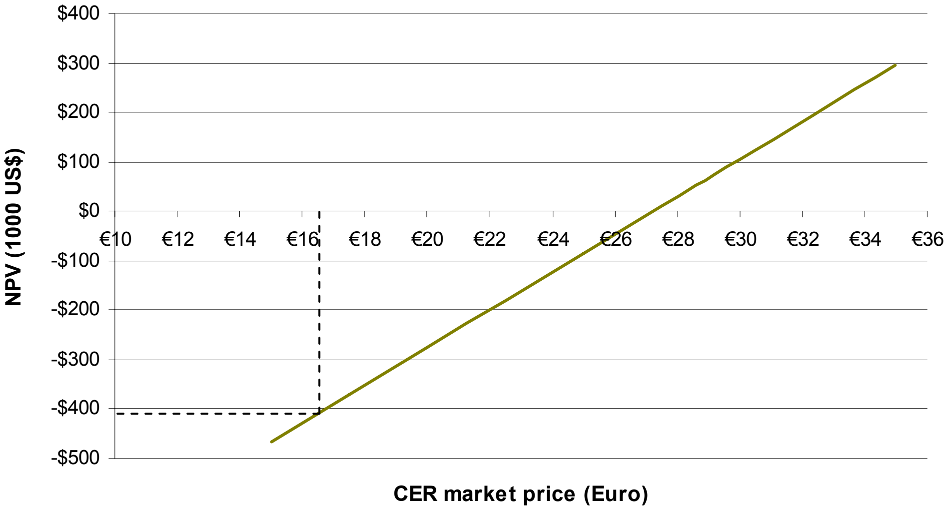

Figure 20: NPV of carbon forestry, as a function of the CER market price. The dashed line indicates the present CER price.

At a MAI of 2 tonne dm/ha/year, the NPV breaks even at a CER market price of €27,24, when mitigating 8 ktonne CO_2 per year. Thus a 65% price increase is needed compared to the present market price. The value of an lCER is coupled to the CER value by the discount rate of the credit buyer. The lCER value is decreasing over the project lifetime, because the period of validity is decreasing (see formula 10). At the start of the project, an lCER has a value of €12,43 for a 30 year validity, compared to a €16,55 for a permanent CER.

On the voluntary market, when assuming a woodland size of 2500 ha, a breakeven is reached at a VER market price of €18,47, which means a needed VER price increase of 85%.

Discount rates have a major impact on cost/benefit analyses and can be prone to significant fluctuations. In recent years in Tanzania, the discount rate has fluctuated from 13% in March 2005 to 21.4% in April 2007. Furthermore, inflation has fluctuated from 3.5% in 2003 to 6.5% in 2006 (Bank of Tanzania 2008). When combining these, the real discount rate may fluctuate between 6.8% and 17.9%. The impact of the applied real discount rate on the NPV of the carbon forestry project is shown in Figure 21:

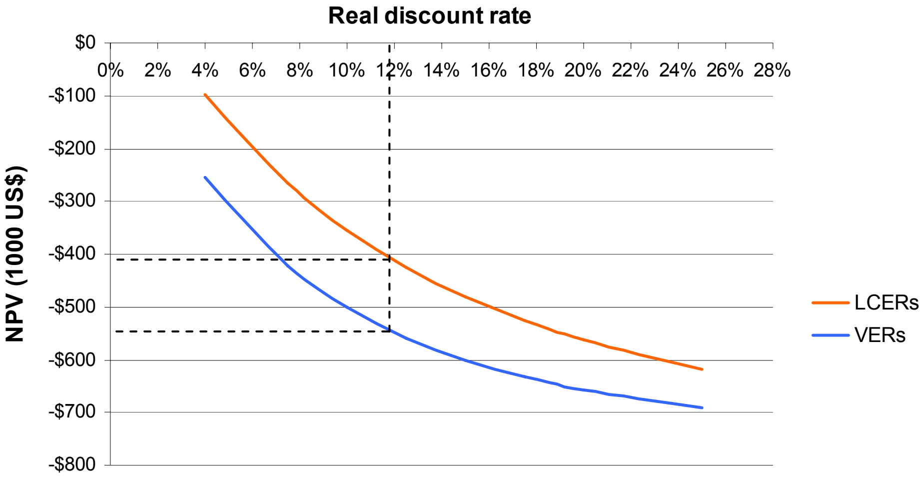

Figure 21: NPV of carbon forestry at an annual CO_2 mitigation of 8 ktonne as a function of the real discount rate, for both trading lCERs and VERs. The dashed lines indicate the present discount rate.

Figure 21 shows the major impact of the applied discount rate on the NPV of the carbon forestry project. This is caused by the fact that high initial investments are needed which have to be earned back by future benefits and over a relatively long time span. Still, even at an attractive discount rate, the project yields a negative NPV.

6.2 Rotational woodlots

6.2.1 Results of the cost/benefit analysis

A total of 16 configurations were analyzed, depending on fuelwood/charcoal/ poles production, monoculture/intercropping, with/without woodfuel tax. The NPV of each configuration for a 1 ha woodlot are presented below:

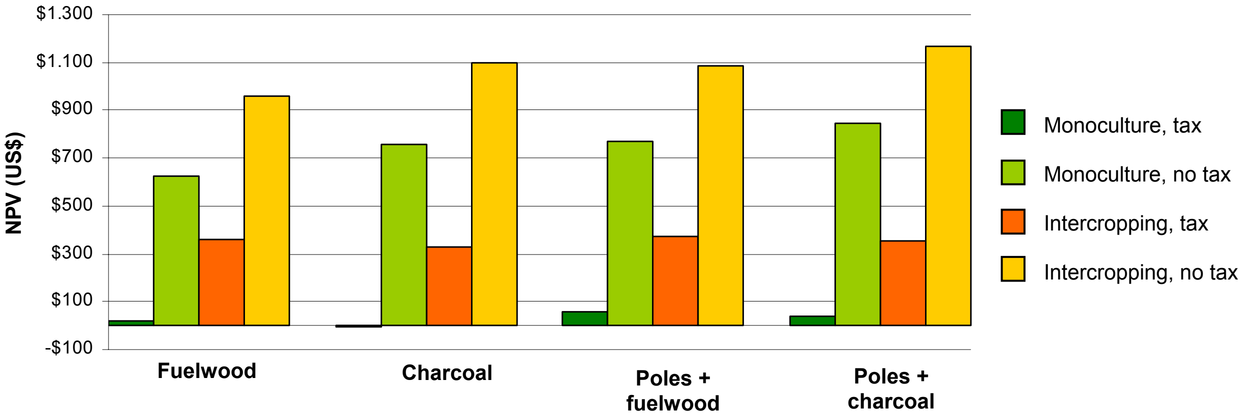

Figure 22: NPV relative to a maize-fallow system, for different wood products of a 1 ha rotational woodlot in semi-arid Shinyanga using *Acacia Polyacantha*, both for a monoculture or intercropped with maize, including and excluding government taxes.

The NPV of rotational woodlots is positive. However the tax burden of both the annual government fee and the payable fees per unit of wood produced is enormous. In a 1 ha monoculture it is hardly economically feasible to establish a woodlot when these taxes are taken into account. The NPV of US$ 761 for charcoal production in a monoculture is completely removed by the taxes. This is mainly because of the high annual government fee, which is independent of the woodlot size. Intercropping adds significantly to the NPV per hectare. This is mainly caused by the maize yield increase after the first rotation, as a result of the improved soil condition. This causes the average annual maize yields per hectare in the rotational woodlot to be even slightly higher as the maize yield in the baseline scenario. However, during the first rotation, maize yields are lower as the baseline and there are costs for the plantation establishment. Trading poles is relatively lucrative. The price of poles per tonne of wood is higher as fuelwood and less labour is needed for wood chopping. Producing poles and charcoal is the economically most attractive option, with an NPV of US$ 1.165 per ha. The Return on labour for all configurations is presented in Figure 23:

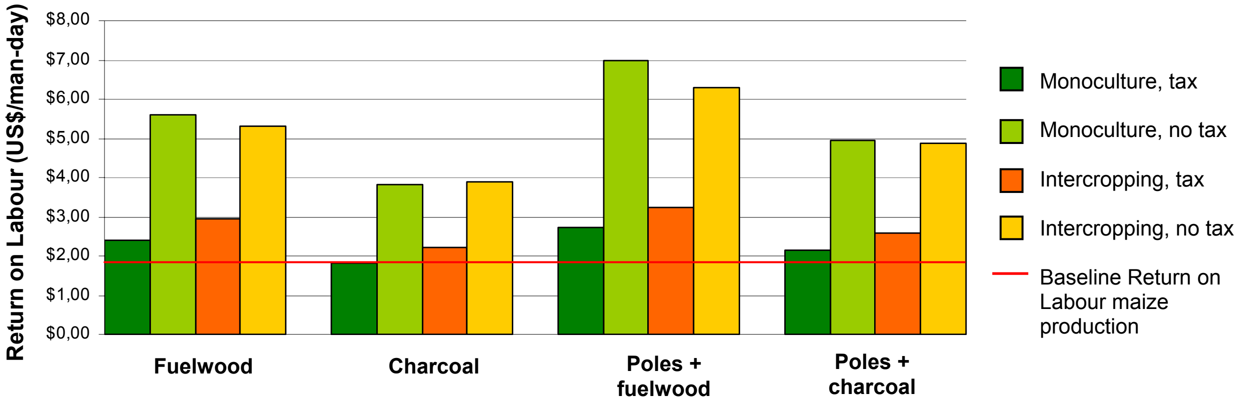

Figure 23: Return on labour for different wood products of a 1 ha rotational woodlot both in a monoculture or intercropped with maize, including and excluding government taxes. The red line indicates the baseline Return on labour for maize cultivation.

The Return on labour is significantly reduced when paying taxes. Furthermore, it is not further increased by intercropping and is maximized for poles and fuelwood production, since this combination has the lowest labour intensity. Thus, a farmer who is constraint by land and wishes to maximize added value per hectare of land is better off when producing poles and charcoal from a woodlot with intercropping, while a farmer with excess land, but a labour constraint is better of when producing poles and fuelwood from a monoculture woodlot. However, this choice is also dependent on access to markets. Figure 24 shows the cost of energy of the produced woodfuel:

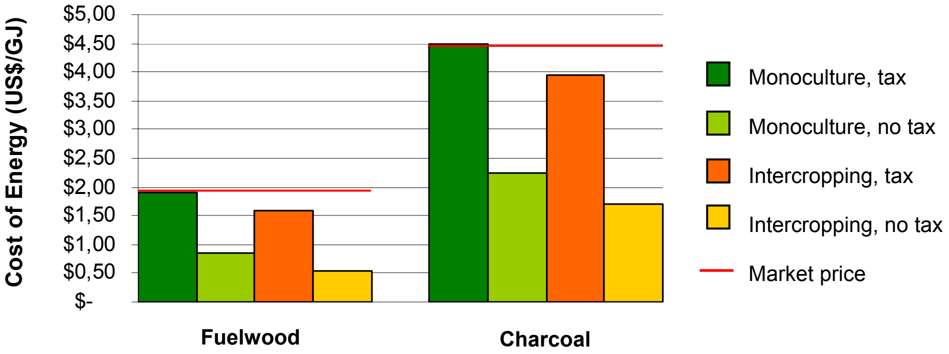

Figure 24: Cost of Energy of fuelwood and charcoal produced from a 1 ha rotational woodlot, both in a monoculture or intercropped with maize, including and excluding government taxes. The red lines indicate the market price of fuelwood and charcoal, respectively.

In case taxes are ignored, the cost of the produced woodfuel energy is significantly lower as the market price. The fuelwood production cost when intercropping is US$ 0,53/GJ, compared to the market price of US$ 1,95/GJ (see Figure 11), a reduction of 73%. The production cost price of charcoal when intercropping is US$ 1,71 per GJ, which is also lower as the market price of fuelwood and which is only 38% of the market price of charcoal. This explains the high NPV of rotational woodlots. In local currency and units, the production cost of woodfuel is Tsh 163 per headload and Tsh 1.914 per bag of charcoal. When taxes are ignored, the Cost of Energy and the Return on Labour are independent of the woodlot size, since there are no fixed investment costs. However, taxes more than double the production cost of woodfuel for a 1 ha woodlot. The cost of utilized heat when cooking on various cooking stoves is shown in Figure 25:

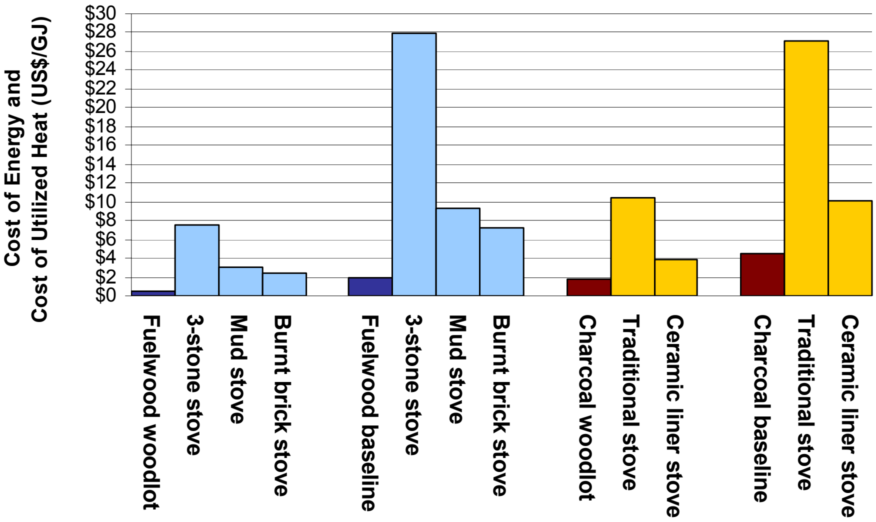

Figure 25: The Cost of energy (dark columns) and the Cost of utilized heat (light columns), for woodfuel produced from a 1 ha woodlot when intercropping, compared to the present market prices in East Shinyanga. Taxes are not included.

Woodfuel produced from the rotational woodlot significantly reduces the cost of utilized heat and narrows the gap between traditional and improved stoves. Cooking on a burnt brick stove is the most economic option, costing US$2,37 per GJ heat. Figure 26 indicates the annual energy production per hectare:

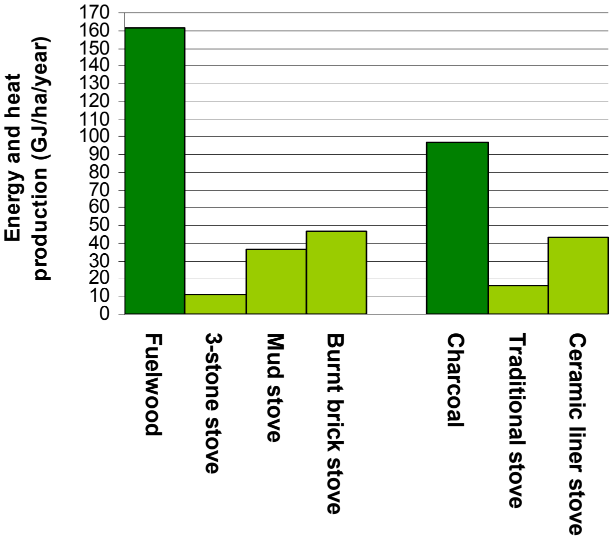

Figure 26: Annual energy production and heat production, using various cooking stoves.

161.5 GJ of fuelwood per hectare can be produced, compared to 97.2 GJ of charcoal, when using a kiln efficiency of 30%. However, when including the stove efficiency, the heat production is about equal for fuelwood and charcoal, under best practise efficiency. With a kiln efficiency of 30% on a weight basis, charcoal production has an energy efficiency of 60%. Added to this an efficiency of 45% for a ceramic stove, gives an overall energy efficiency of 27%, which is about the efficiency of cooking on fuelwood using a burnt brick stove. A one hectare woodlot would provide enough fuelwood to fulfil the annual fuelwood demand of 1.3 households in Shinyanga, when using the current average cooking efficiency of 8%. When improving the efficiency to 29% with burnt brick stoves, 4.6 households can be provided with energy. For charcoal this is 1.5 and 4.2 households for traditional and ceramic charcoal stoves, respectively.

Figure 27 depicts a breakdown of the annual labour needed in the rotational woodlot when producing poles and charcoal after year 7, when a constant annual wood supply is realized. Figure 28 shows a breakdown of the annual benefits of this configuration after year 7:

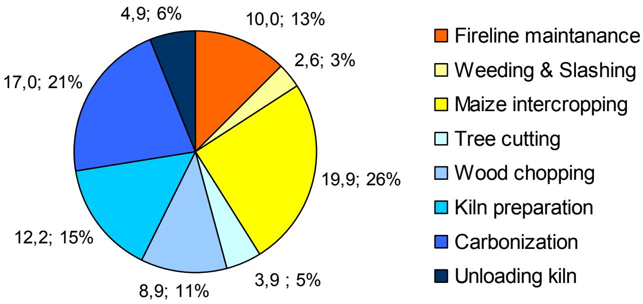

Figure 27: Breakdown of annual labour needed for poles and charcoal production after year 7, when a constant wood supply is realized, both in absolute values (man-days/ha/year) and relative values. The total annual labour is 79 man-days/ha/year.

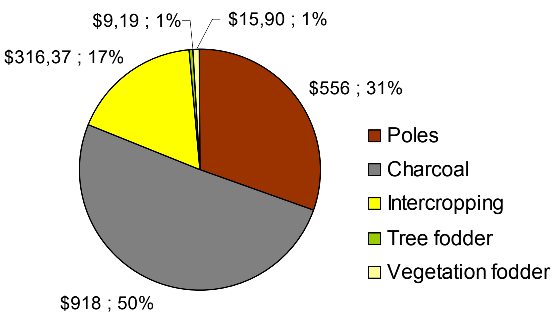

Figure 28: Breakdown of the annual benefits of poles and charcoal production after year 7, both in absolute values (US$/ha) and relative values.

Charcoal production is labour intensive and accounts for 58% of the annual labour needed. However, it also contributes to 50% of the annual benefits. Intercropping adds a significant benefit, while the benefits of both leguminous and vegetation fodder are insignificant. After the rotational woodlot is fully established in year 7, in total 79 man-days/ha/year are needed, compared to 70 man-days/ha/year for maize cultivation in the baseline. Thus, with adding 9 man-days/ha, an additional NPV of US$ 1.165/ha can be realized, compared to sole maize production. Furthermore, tree harvesting and charcoal production can be practised during the agricultural off-season so that labour competition with food production is avoided and the farmer has time to cultivate more land during the agricultural season. The annual labour needed for sole fuelwood production, charcoal production or poles and fuelwood production after year 7 is 50, 107 and 45 man-days/ha/year, respectively, when intercropping.

The labour intensity of fuelwood production is 0.26 and 0.22 man-days/GJ for a monoculture and for intercropping, respectively. Converted to local units, this is about 29 minutes of labour per headload, indicating the time that can be saved on fuelwood collecting when producing fuelwood from a woodlot, since in East Shinyanga, fuelwood collecting can take several hours per headload. Charcoal production is significantly more labour intensive: 2.05 man-days/GJ for a monoculture and 1.91 man-days/GJ when intercropping.

The investment costs for seedlings and manure during the years of tree planting are US$ 15,50/ha annually. A breakdown of the NPV of the total lifetime costs of the rotational woodlot, when producing poles and charcoal is shown in Figure 29, both with and without taxes:

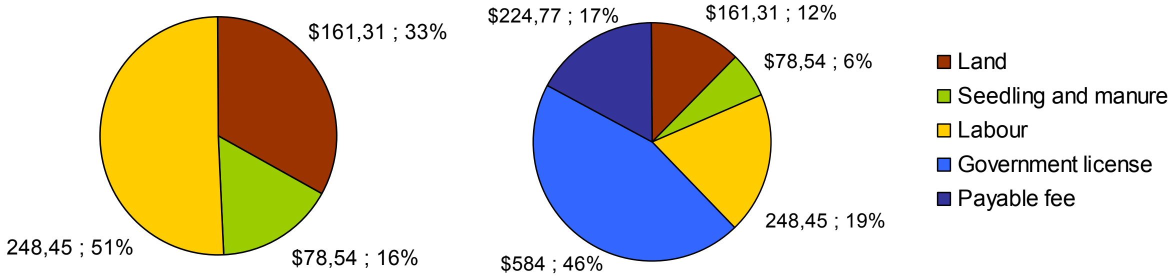

Figure 29: Breakdown of the NPV of the total lifetime costs of a 1 ha rotational woodlot for producing poles and charcoal. The right pie shows the costs when taxes are added.

Without taxes, the shadow cost of labour is the largest cost factor, followed by the opportunity cost of land. However, when taxes are included, these account for 62% of the NPV of the total production costs.

6.2.2 Sensitivity analysis

The most important parameters are subject to a sensitivity analysis. These are the woodlot size, the MAI, the shadow cost of labour, the kiln efficiency and the discount rate.

In case taxes are ignored, the economic feasibility of the rotational woodlot is independent of the woodlot size. However, the government fee on woodfuel production is independent of the woodlot size and is thus fixed. When taxes are included, the total costs decrease and the Return on labour increases with an increasing woodlot size, as shown in Figure 30:

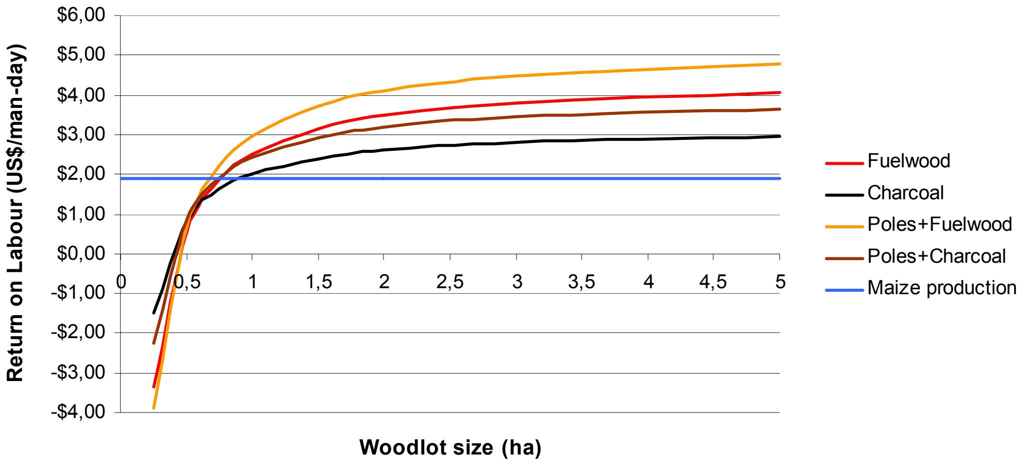

Figure 30: Return on Labour for the rotational woodlot with intercropping and tax payment, as a function of the woodlot size.

The figure shows that only at a woodlot size of 0.5–1 ha, the Return on Labour is breaking even with maize production. However, what the figure does not show is that at a size of 1 ha, the reduction in the Return on labour because of taxes is still 43–48%. When applying intercropping, only at a woodlot size of 3.4 ha and 16 ha, the tax burden is decreased to the Tanzanian VAT of 20%, for fuelwood production and charcoal production, respectively. Though, even a woodlot size of 3.4 ha is rather large for smallholders.

Since the MAI of this analysis is only based on one experiment in Shinyanga (Nyadzi *et al.* 2003), the uncertainty is rather high. The impact of the MAI on the Return on labour is presented below:

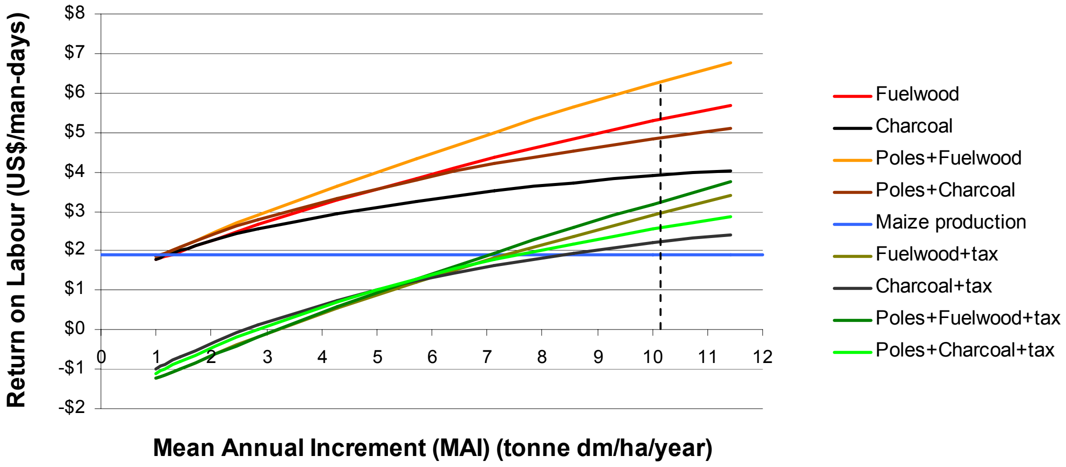

Figure 31: Return on Labour of the rotational woodlot with intercropping, as a function of the MAI. The dashed line indicates the present MAI.

The present MAI is 10.1 tonne dm/ha/year. At a MAI of around 1.3 tonne dm/ha/year, the Return on Labour will break even with maize production. However, when taxes are included, the breakeven MAI is increased to 7–8.5 tonne dm/ha/year for a 1 ha woodlot. Thus, only when trees are growing relatively fast, a rotational woodlot is economical when taxes are included. The impact of the MAI on the production cost of energy is depicted in Figure 32:

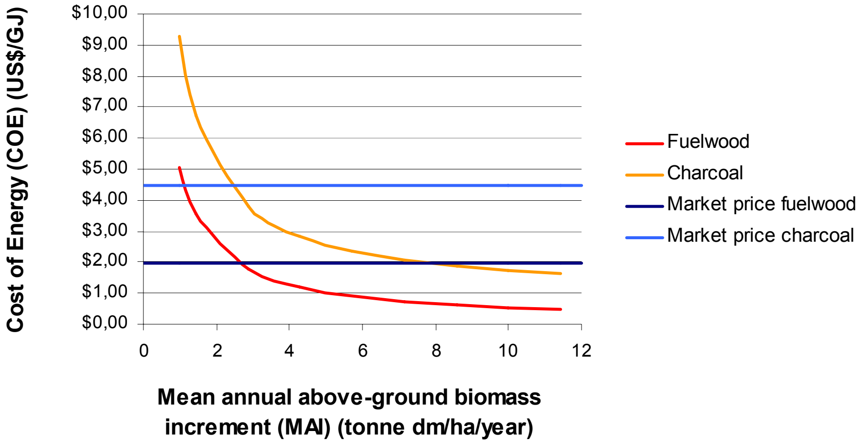

Figure 32: The cost of woodfuel energy, as a function of the MAI.

In the absence of fixed investment costs and with tree cutting and wood processing labour being independent of the MAI, the Cost of Energy is rather insensitive towards a reduction of the MAI; up to the point were the MAI drops below 4 tonne dm/ha/year. The market price breakeven point is at a MAI of 2.9 and 2.5 tonne dm/ha/year for fuelwood and charcoal, respectively. However these values are quickly increased with decreasing market prices. These breakeven points are higher as the breakeven MAI for the Return on Labour, since the benefits of intercropping are assumed to be independent the MAI.

Because labour costs are the largest cost factor, the sensitivity of the NPV towards the shadow cost of labour was analyzed. The results are depicted in Figure 33:

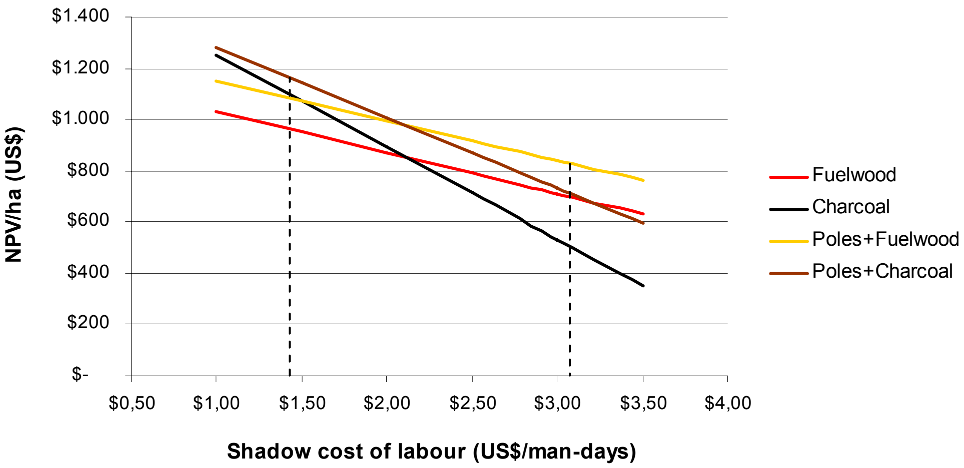

Figure 33: The NPV per ha of the rotational woodlot with intercropping, as a function of the shadow cost of labour. The left dashed line indicates the baseline shadow cost of labour. The right dashed line indicates the official Tanzanian minimum wage rate.

Charcoal production is relatively labour intensive and is thus relatively sensitive towards the shadow cost of labour. When the official Tanzanian minimum wage rate would apply, the charcoal NPV would decrease with 55%. However, none of the configurations show a negative NPV when the shadow cost of labour increases to this rate. Charcoal production increases the NPV of the rotational woodlot. However, in this analysis an earth kiln efficiency of 30% is assumed, which is best practice efficiency, that can only be achieved under optimal kiln management. The average earth kiln efficiency in Tanzania is 19% (Malimbwi *et al.* 2007). The sensitivity of the NPV towards the kiln efficiency is depicted below:

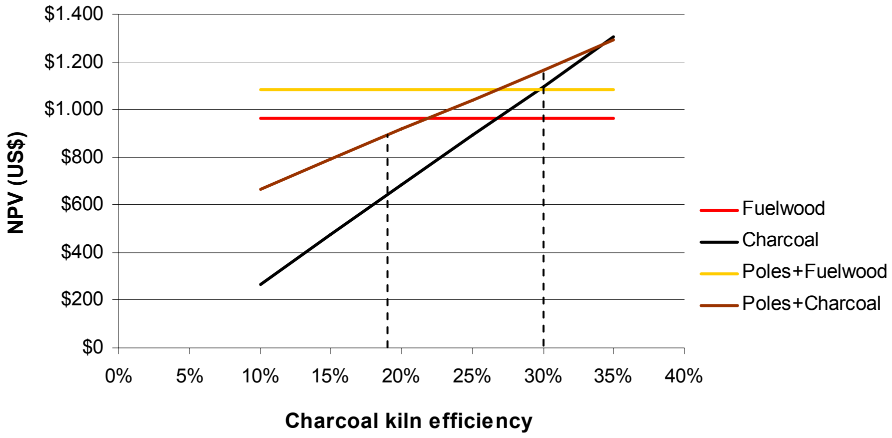

Figure 34: The NPV of the rotational woodlot with intercropping, as a function of the charcoal kiln efficiency. The left dashed line indicates the current average kiln efficiency. The right dashed line indicates the assumed best practice kiln efficiency.

The NPV is rather sensitive towards the kiln efficiency. Producing charcoal is only attractive, compared to producing fuelwood, at a kiln efficiency of 27%, which is far above the average in Tanzania. The reason might be the relatively large wood scarcity in semi-arid Shinyanga, causing fuelwood to be scarce and thus relatively expensive, while the demand for charcoal is relatively low compared to areas with less wood scarcity, which results in relatively low charcoal prices. In areas with less wood scarcity, the gap between the fuelwood and charcoal price might be much larger. Furthermore, local acacia charcoal is less preferred compared to charcoal from the miombo woodlands of west Shinyanga and Tabora region. At last, the effect of the discount rate on the NPV per hectare was analyzed:

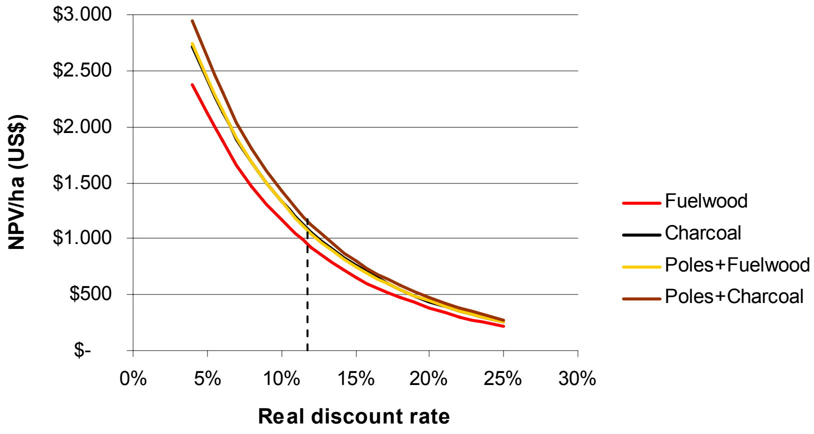

Figure 35: The NPV per hectare of the rotational woodlot, as a function of the real discount rate. The dashed line indicates the applied real discount rate.

An increased discount rate significantly reduces the NPV per hectare; however, even for a rate of 25%, the NPV is positive for all configurations.

6.3 Jatropha oil production

6.3.1 Results of the cost/benefit analysis

The costs and benefits of Jatropha cultivation were assessed both for a monoculture on degraded land and for intercropping in the first five years on arable land. Furthermore, the opportunities of trading seeds, trading oil or utilizing the oil for cooking, electrification or soap production were taken into account. The main results of the cost/benefit analysis are presented below:

Parameter	Unit	Monoculture	Intercropping
OPTION 1: JATROPHA SEED TRADE			
Production cost	US$/tonne	98,45	97,55
	Tsh/kg	119	118
Return on Labour	US$/man-day	1,28	1,32
NPV	US$/ha	-229	-180
JATROPHA OIL PRODUCTION			
Production cost	US$/litre	0,73	0,75
Annual energy production*	GJ/ha/year	30.9	25.8
Labour intensity	Man-days/GJ	10.1	10.1
Annual labour needed*	Man-days/ha/year	299	252
OPTION 2: COOKING ON JATROPHA OIL			
Cost of Energy	US$/GJ	19,60	19,98
Cost of utilized heat	US$/$GJ_H$	44,99	45,83
Utilized heat	GJ_H/ha/year	13.9	11.6
NPV	US$/ha	-1.361	-1.179
Return on Labour	US$/man-day	0,62	0,59
OPTION 3: TRADING JATROPHA OIL			
NPV	US$/ha	47,02	-6,28
Return on Labour	US$/man-day	1,53	1,41
OPTION 4: ELECTRICITY PRODUCTION			
Production cost of electricity	US$/GJ	166,14	171,85
	US$/kWh	0,60	0,62
Annual electricity production*	kWh/ha/year	2.320	1.933
Electrification	Households/ha	5.5	4.6
NPV when replacing diesel	US$/ha	2.113	1.616
Return on Labour replacing diesel	US$/man-day	2,85	2,68
OPTION 5: SOAP PRODUCTION			
Production cost	US$/kg	0,92	0,93
NPV	US$/ha	23.232	19.310
Return on Labour	US$/man-day	10,59	10,68

Table 22: Results of the cost/benefit analysis for Jatropha oil production for a plantation size of 1 ha. (* At maximum seed yield from year 9 and onwards.)

The production cost of Jatropha seeds is higher as the market price of Tsh 100 per kg, which results in a negative NPV and a Return on Labour which is lower as the baseline Return on Labour. The opportunity cost of land is about equal for monoculture or intercropping, because the benefit of intercropping on arable land is levelled out by the lower opportunity cost of degraded land. This causes the production cost of seeds to be basically equal for monoculture and intercropping. However, the NPV per ha diverges, because of the difference in spacing between a monoculture plantation and an intercropped plantation. On a monoculture plantation, the spacing is denser so that more seeds are produced per hectare and thus more labour is needed.

The production cost of Jatropha oil in a monoculture plantation is US$ 0,73 per litre. This is slightly below the assumed local market price of US$ 0,75 per litre, so that a slightly positive NPV can be achieved, however the benefit per man-day of work is lower as the baseline. This is caused by the fact that Jatropha oil production is very labour intensive. Cooking on Jatropha oil is not economical compared to cooking on fuelwood, because the cost of utilized heat of Jatropha oil is significant, as shown in Figure 36:

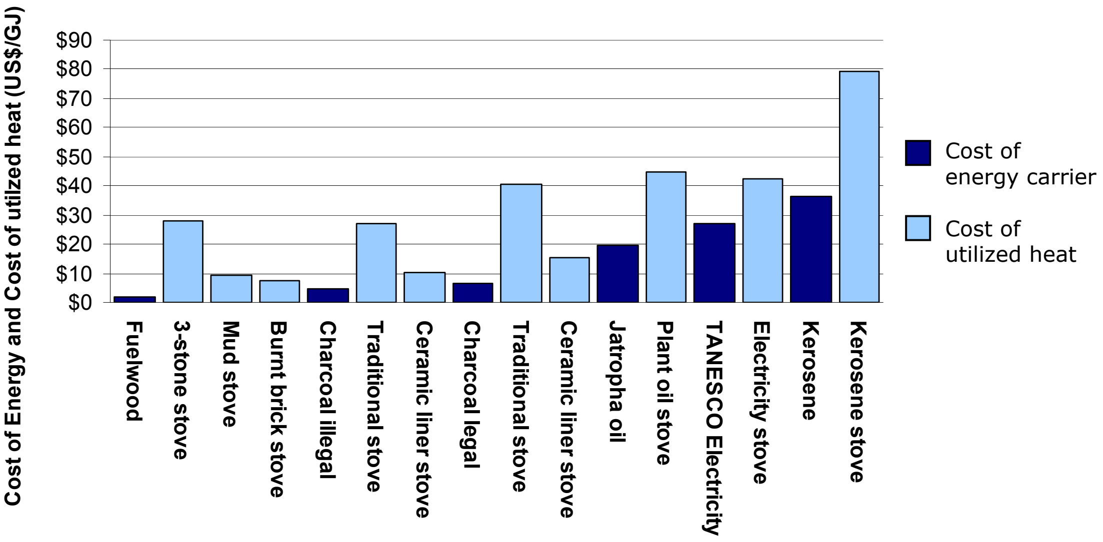

Figure 36: Cost of energy for household cooking in rural East Shinyanga, both in terms of primary energy (dark blue columns) and utilized heat (light blue columns), using various cooking stoves. The cost of energy carriers in terms of primary energy is shown in order of magnitude.

Figure 36 resembles to Figure 11 but is complemented with Jatropha oil. The Cost of energy of Jatropha oil is in between legal charcoal and electricity from a TANESCO rural electrification project. However, because of the high efficiency of the Jatropha cooking stove, the cost of utilized heat is only slightly higher as cooking on a traditional charcoal stove. Clearly, Jatropha oil as a cooking fuel is far more expensive compared to wood or charcoal produced from a rotational woodlot.

The Net Present Value of using Jatropha oil for electrification is relative to using diesel as a generator fuel and consists of the difference in cost between diesel and Jatropha oil, minus the costs of adapting the generator. The relatively high NPV and Return on Labour are caused by the fact that the production cost of Jatropha oil is about 50% less expensive than the market price of conventional diesel in rural Shinyanga. The cost of electricity is US$ 0,60 per kWh, compared to US$ 0,79 per kWh, when using diesel, a cost reduction of 24%. Still, US$ 0,60 per kWh is about 6 times more expensive as the subsidized cost of electricity in case of a TANESCO rural electrification project (see Table 13) and is not likely to be affordable for many people. In Figure 37, a breakdown of the annual costs of electricity production using Jatropha oil at a maximum seed yield is shown:

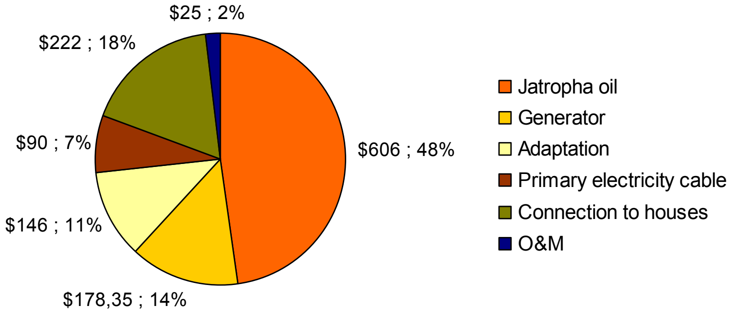

Figure 37: Breakdown of annual electricity production costs when using Jatropha oil from a 1 ha monoculture plantation.

The fuel costs account for 48% of the total annual costs. The generator adaptation for using Jatropha oil as a fuel is a relatively large cost factor, since there is no market for such services yet.

Jatropha soap production turns out to be very profitable. When investing limited labour and cash, significant value can be added to the Jatropha oil. However, the local market for Jatropha soap is insignificant, though, in urban areas there can be a larger market. In Arusha, a shop is selling Jatropha soap as a luxury product (Matchmaker 2007). Although it can be expected that when this market would grow and develop more, the farm-gate price of Jatropha soap will decrease because of competition effects.

As indicated before, Jatropha oil production is very labour intensive. A breakdown of the labour needed for both seed production as oil production is given below:

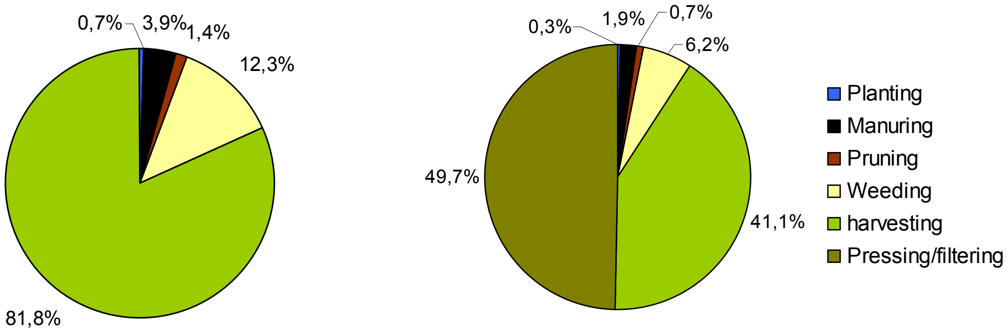

Figure 38: Breakdown of total labour needed for Jatropha seed production (left pie) and oil production (right pie) over the lifetime of a 1 ha intercropped plantation.

Almost 82% of the total labour needed for seed production is seed harvesting labour, which includes dehulling of the fruit. The labour needed for manual oil pressing and oil filtration is even larger as the labour needed for seed harvesting. Both account for 91% of the labour needed for small-scale Jatropha oil production. On average 3 hours are needed for the production of one litre of Jatropha oil. In total 299 man-days are needed per year and per hectare to run the monoculture plantation under maximal production, compared to 70 man-days per hectare for maize cultivation in the baseline. A cost breakdown of Jatropha oil production for the purpose of household cooking on a 1 ha plantation is depicted in Figure 39:

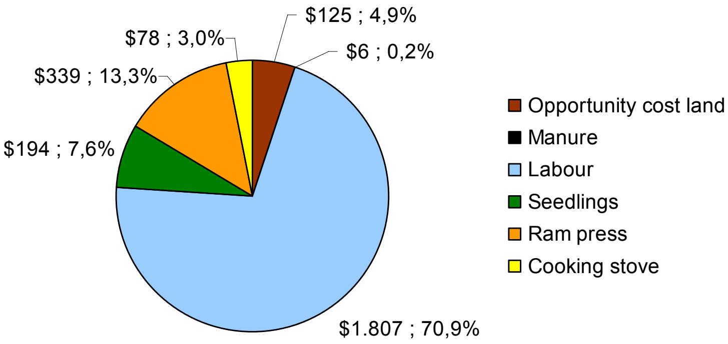

Figure 39: Breakdown of the NPV of the costs of household cooking on Jatropha oil over the lifetime of the plantation when produced from a 1 ha intercropped plantation.

Labour costs account for 71% of the total costs, of which 91% is labour for seed harvesting and oil pressing. When excluding the Jatropha stove costs, 66% of the production costs of Jatropha oil are labour costs for harvesting and oil pressing, which are independent of the seed yield. The plant oil cooking stove accounts for only 3% of the total costs. The cost for the ram press is fixed, which results in declining production costs of Jatropha oil when increasing the plantation size.

6.3.2 Sensitivity analysis

The results will be tested on sensitivity towards the Jatropha seed yield, the plantation size, the shadow cost of labour, the cost of fuelwood and the applied discount rate. Figure 40 shows the production cost of oil and seeds as a function of the maximum obtained Jatropha seed yield:

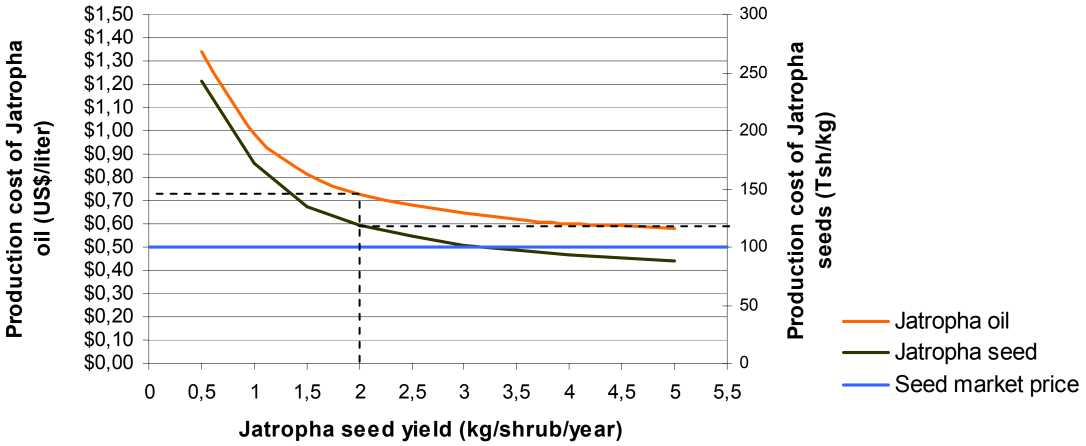

Figure 40: The production cost of Jatropha seeds (right axis) and Jatropha oil (left axis), as a function of the maximum annual Jatropha seed yield per shrub, for a 1 ha monoculture plantation. The dashed line indicates the estimated maximum annual seed yield.

The sensitivity of the production cost as a function of the seed yield is declining with increasing yields, because 66% of the production costs are variable labour costs for harvesting and pressing, which are assumed to be independent of the seed yield. A maximum yield of 1.5 instead of 2 kg/shrub/year would result in an oil production cost increase of 11%. Only at a seed yield of 3.2 kg/shrub/year, the seed production cost will break even with the seed market price. The impact of the plantation size on the production cost of Jatropha oil is depicted below:

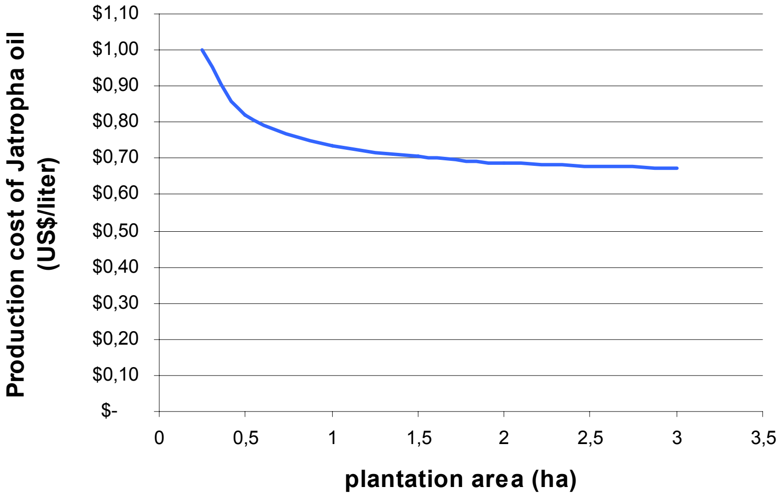

Figure 41: The production cost of Jatropha oil as a function of the plantation area for a monoculture plantation.

The maximum capacity of a manual ram press is 5 kg of seed per hour (Henning 2004), which corresponds to a plantation size of about 3 ha with a seed yield of 2 kg/shrub/year. At such a plantation size, the production cost of oil is decreased with 8.2% to US$ 0,67 per litre, compared to a 1 ha plantation. At plantation sizes below 1 ha, the production costs increases rapidly because of the fixed investment cost of the ram press. Figure 42 shows the sensitivity of the NPV of cooking on Jatropha oil towards the market price of fuelwood:

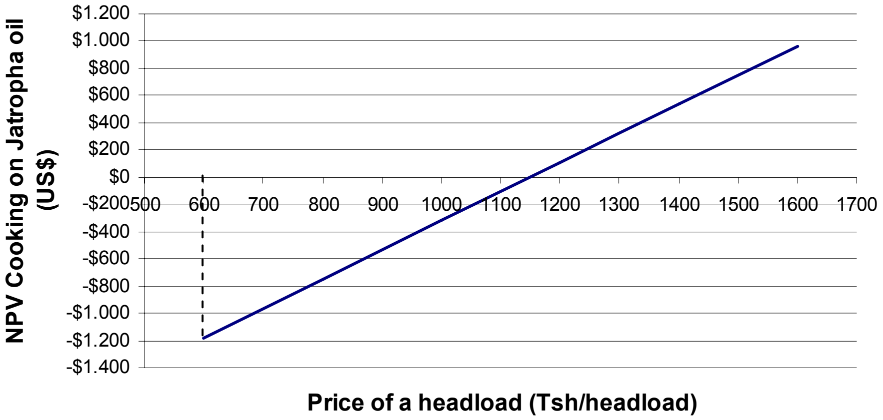

Figure 42: The NPV of cooking on Jatropha oil as a function of the market price of fuelwood for a 1 ha monoculture plantation. The dashed line indicates the present market price.

Only at a market price, or a shadow cost, of Tsh 1.129 per headload, or US$ 3,68 per GJ, the benefit of avoided fuelwood consumption is large enough for the Jatropha plantation to become economically feasible. Thus a 88% fuelwood price increase is needed, which is not very likely. However, the shadow cost of fuelwood differs per area. In remote and heavily deforested areas the shadow cost of fuelwood might be significantly higher as the assumed market price.

Because of the labour intensity of Jatropha oil production, the impact of the shadow cost of labour on the production cost of Jatropha oil is significant, as illustrated in Figure 43:

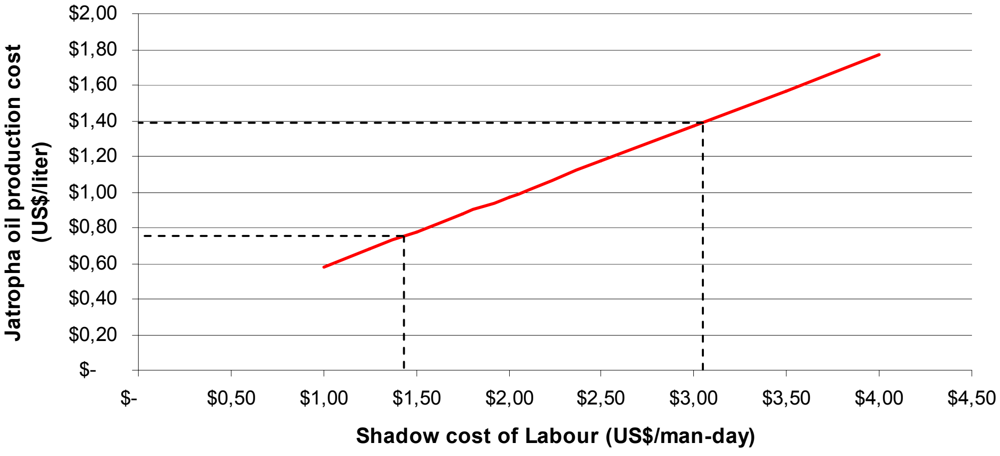

Figure 43: The production cost of Jatropha oil as a function of the shadow cost of labour for a 1 ha monoculture plantation. The left dashed line indicates the estimated shadow cost of labour. The right dashed line indicates the official Tanzanian minimum wage.

In case the estimated shadow cost of labour is increased to the value of the official Tanzanian minimum wage rate of US$ 3,06 per man-day, the oil production cost will increase with 90%, to US$ 1,39 per litre. At a shadow cost of labour of US$ 1,35 per man-day, trading Jatropha seeds for a market price of Tsh 100/kg, breaks economically even with a maize-fallow system and oil is produced for US$ 0,64 per litre.

At last, the impact of the real discount rate on the production cost of oil is determined:

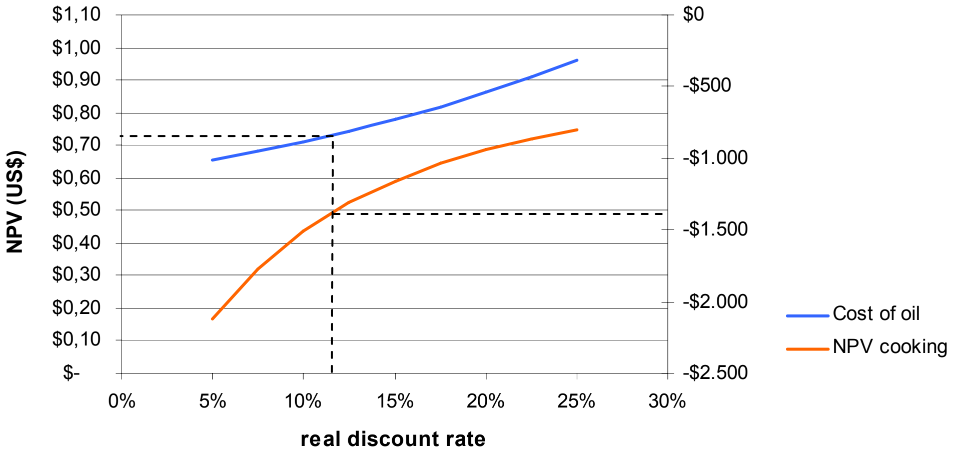

Figure 44: The production cost of Jatropha oil (left axis) and the NPV of cooking on Jatropha oil (right axis), as a function of the applied real discount rate for a 1 ha monoculture plantation. The dashed line indicates the applied real discount rate.

A real discount rate of 20% would lead to an oil production cost increase of 18%. The impact of the discount rate is less significant compared to rotational woodlots, because at the Jatropha plantation, costs and benefits are relatively spread over the lifetime of the plantation. The main costs, the labour costs for seed harvesting and oil pressing, are made every year, while the benefit of oil production is also obtained every year instead of once in 7 years. The NPV of cooking on Jatropha oil is never positive. However, the negative value increases for an increasing discount rate. This is caused by the high annual labour cost for harvesting and pressing. A lower discount rate leads to higher future labour costs.

7. Synthesis and discussion

7.1 Comparison of results

In the previous chapter, the results of the cost/benefit analysis were presented, including sensitivity analyses of the impact of the most dominant and uncertain input parameters. However, this analysis is carried out per system and for each individual parameter. In this section, the results of the cost/benefit analysis will be compared, including the total accumulated uncertainty when combining the uncertainty in the input parameters. For this analysis, the following uncertainty ranges were used:

Parameter	**Unit**	**Base case**	**Max**		**Min**	
Shadow cost of labour	US$/man-day	1,43	3,06	(114%)	1,00	(30%)
Real discount rate	-	11.8%	17.9%	(51%)	6.8%	(42%)
Headload of fuelwood cost	Tsh/headload	600	800	(33%)	400	(33%)
MAI Carbon forest	Tonne dm/ha/year	2	3	(50%)	1	(50%)
CER market price	Euro/CER	16.55	20	(21%)	10	(40%)
MAI woodlot	Tonne dm/ha/year	10.13	12	(18%)	5	(51%)
Kiln efficiency	-	30%	30%	-	10%	(67%)
Max. Jatropha seed yield	Kg/shrub/year	2	1	(50%)	3	(50%)
Jatropha plantation size	hectare	1	3	(200%)	0.41	(59%)

Table 23: Uncertainty in the parameters used in the sensitivity analyses.

The uncertainty in the shadow cost of labour is assumed to vary from the international poverty line of US$ 1 per man-day, to the official minimum wage rate of US$ 3,06 per man-day. The uncertainty in the real discount rate is determined as indicated in paragraph 6.1.2. The base case woodlot MAI is relatively high since *Acacia Polyacantha* is a relatively fast growing species. Therefore, the uncertainty ranges more towards lower MAI values. Best practise charcoal kiln efficiency was used for this research, though the kiln efficiency can decrease to 10% in case of bad kiln management. The Jatropha plantations size varies from 1 acre to 3 hectare, which is the maximum capacity of the ram press in the base case. The uncertainty values of the other parameters are based on estimates. The NPV per hectare of each system is pictured in Figure 45, including the error bars for total accumulated uncertainty.

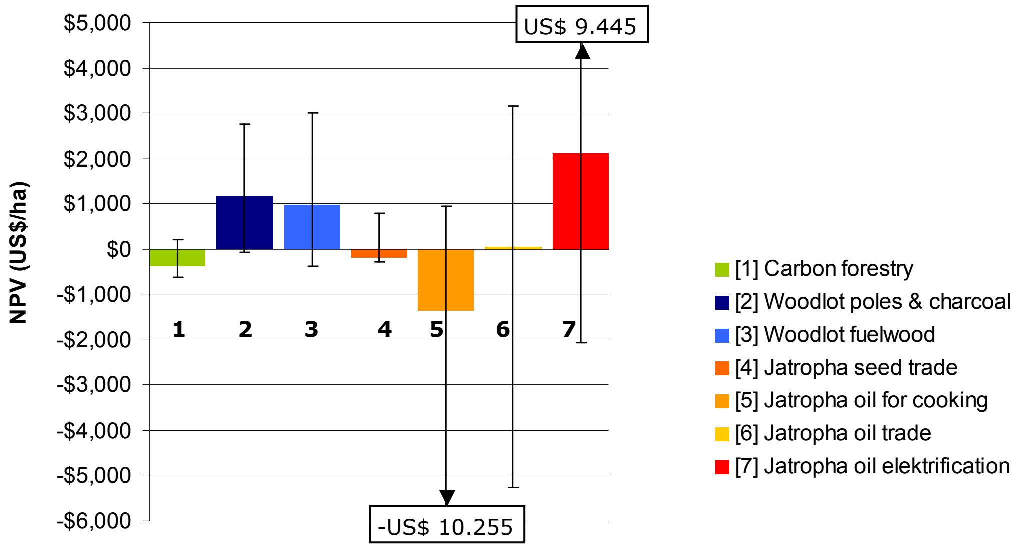

Figure 45: System comparison of the NPV per hectare, including error bars. Woodlots are intercropped. The baseline NPV of maize cultivation is defined as zero, compared to these systems.

Jatropha oil production as a substitute for diesel in an off-grid electrification project is the most profitable option per hectare, though Jatropha oil trade is economical as well. The error ranges for all Jatropha oil options are relatively large. This is mainly caused by the uncertainty in the shadow cost of labour, since smallholder Jatropha oil production is labour intensive. When land workers are paid the minimum wage rate, even electrification becomes strongly uneconomical. For household cooking, only rotational woodlots show a positive NPV as a source of sustainable biomass energy. The NPV of woodlots can become negative when the wood yield and the market price of fuelwood are relatively low and labour cost and discount rate are relatively high. Similarly, the NPV of carbon forestry can become positive with a high MAI and a low discount rate. A comparison of the Return on labour is depicted in Figure 46:

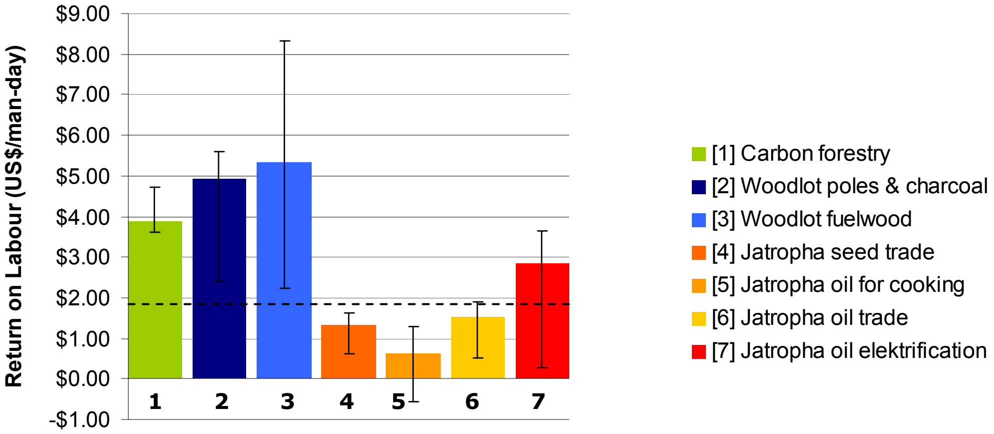

Figure 46: System comparison of the Return on labour. The dashed line indicates the baseline Return on labour of a maize-fallow system.

Error margins are less wide compared to the NPV, because the shadow cost of labour does not have an impact on the Return on labour, while it has a strong impact on the NPV. The Return on labour is always above the baseline for both carbon forestry and rotational woodlots, as opposed to Jatropha, where the Return on labour is always below the baseline, except for electricity production. Electricity production yields the highest NPV per hectare, but has a lower Return on labour compared to rotational woodlots. In Figure 47 the Cost of energy is compared:

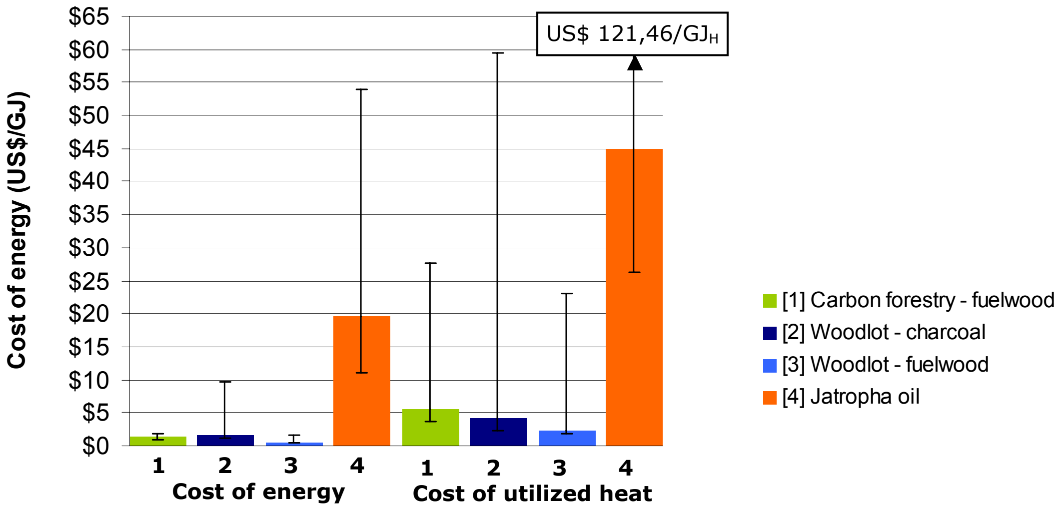

Figure 47: System comparison of the cost of energy and the cost of utilized heat for household cooking.

The production cost of Jatropha oil is significantly larger compared to fuelwood or charcoal from carbon forestry or woodlots. Jatropha oil can be considered a higher quality fuel and it is thus not economical to burn it just for heat production, since fuelwood and charcoal are much cheaper alternatives. Jatropha oil can better be utilized as a diesel substitute. Error ranges are high for charcoal because of the variation in kiln efficiency and for Jatropha oil because of the variation in the shadow cost of labour. With a low kiln efficiency of 10% and when paying the minimum wage rate, the cost of charcoal can go up to US$ 9,80/GJ, or Tsh 10.950 per bag. The production cost of Jatropha oil is determined to be US$ 0,73 per litre with an error range between US$ 0,42 and US$ 2,02 per litre. The uncertainty range of Jatropha seed production varies between Tsh 69 and Tsh 351 per kg, compared to Tsh 118 per kg in the base case. The latter is not depicted in Figure 47, however momentarily Jatropha seed is the largest Jatropha-related market in Tanzania and thus uncertainties in the production cost price are of importance. The error ranges in the cost of utilized heat include variations in stove efficiency, which may vary from 7% to 45% for a 3-stone stove and a ceramic stove, respectively (see appendix A).

The production cost of off-grid electricity using Jatropha oil was deliberately not included, because it is regarded as a much higher quality energy carrier which is not likely to be used for powering an electric cooking stove. Thus, a comparison based on the cost per GJ would be misleading. Based on the assumed input parameters, the production cost is US$ 0,60 per kWh, or US$ 166 per GJ, with an error range between US$ 0,38 and US$ 1,49 per kWh. This error range is based on the input parameters in Table 23 and does not include uncertainty in investment costs.

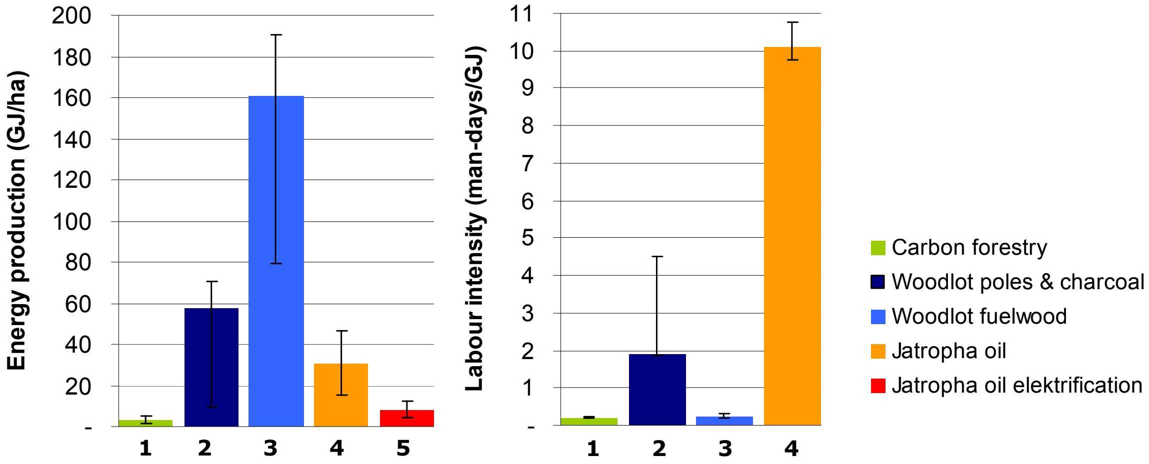

Figure 48: System comparison of the energy production per hectare and the labour intensity per GJ.

Wood production using a rotational woodlot is highly productive in terms of primary energy per hectare. However, as indicated before, Jatropha oil and electricity are much higher quality energy carriers. When maximizing cash profits in a rotational woodlot, poles are produced from the tree stems and the branches are converted to charcoal, which explains the relatively low charcoal energy production. Based on the assumption of a fuelwood harvest of 10% of the MAI, carbon forestry yields little energy per hectare. However, a carbon forest is multifunctional and the main focus is not on energy production. Jatropha oil production is very labour intensive, compared to woodfuel production. The large error range in the labour intensity of charcoal production is caused by the variation in kiln efficiency.

7.2 Discussion

7.2.1 Carbon forestry

Local fuelwood supply by means of a carbon forestry project is not economically feasible in semi-arid Shinyanga. The MAI is too low and risks of fire are too high so that the specific costs per hectare are larger as the benefits of carbon trade and fuelwood production. By reserving 10% of the annual growth increment for fuelwood, at an average cooking efficiency of 8%, the 1558 ha of carbon woodland can satisfy the fuelwood demand of 39 households, or 261 persons. Furthermore, there are many additional forest benefits, that are not taken into account in this cost/benefit analysis (see Figure 12). A carbon woodland in semi-arid Shinyanga has the potential to fulfil an important socio-economic function for a local community, by providing various forest products, like leguminous fodder, honey from bee-keeping, meat, mushrooms, ropes, medicines, etc. In addition, there are indirect benefits like reduced deforestation, biodiversity increase and reclamation of degraded land. Especially the latter is valuable concerning the alarming state of land degradation in semi-arid Shinyanga.

Relevant data on the economic value of all forest products per hectare of planted woodland was not available. Monela *et al.* did an economic valuation of *Ngitili* and determined the implicit value of these regenerated grazing lands to be US$ 14 per person per month (2005). However, it is hard to indicate whether a regenerated *Ngitili* would provide the same benefits as a planted woodland. Furthermore, the value per hectare was not indicated in this study. When this value of US$14 per person per month would be converted to the 39 households that could be sustained by the produced fuelwood, the NPV of the total benefit for these households becomes US$ 224.640 over the lifetime of the project, which is US$ 144 per hectare of woodland and would increase the NPV per hectare from US$ -261 to US$ -117 per hectare. The local value of forest products is thus significant. However, this is an economic valuation of non-monetary goods, expressed in monetary terms and it is not a financial benefit for an investor.

Nevertheless, from an institutional perspective, carbon forestry can be an attractive strategy to improve the socio-economic situation of local communities in Shinyanga and to combat land degradation. These two can be regarded as the same problem, however considering the severe state of land degradation in Shinyanga and the urgent need to combat this process, it is specifically mentioned here. When including all these non-monetary benefits, donor organizations might be willing to finance the gap between costs and benefits of carbon forestry. Based on the presented input data, at a woodland size of 1558 ha, about 50% of the forestation costs can be financed by the trade in lCERs, leaving a gap of about US$ 400.000, or US$ 261 per hectare.

The sensitivity analysis shows that small-scale forestation under the CDM is only economically feasible at a MAI of more than 5 tonne per ha, because of the cap of 8 ktonne on the annual CO_2 mitigation. When this cap would be set to 10 ktonne per ha, for example, the NPV breakeven point is reached at a MAI of 4 tonne per ha. Thus, the cap of 8 ktonne significantly reduces the applicability of the small-scale forestation methodology under the CDM. It only allows projects in areas with a high MAI, while most poverty is experienced in drier areas with lower MAI. In their analysis on the feasibility of small-scale CDM forestation projects, Locatelli and Pedroni came to a similar conclusion (2006). At the moment, the UNFCCC is studying this issue (UNFCCC 2007c). The impact of the MAI on the NPV of carbon forestry as shown in Figure 18 and Figure 19 is slightly flawed, since it is likely that in areas with a higher MAI, land will have a higher value, compared to the opportunity cost of land in Shinyanga. On the other hand, forest fire prevention is likely to be less important in those areas.

In this study it was assumed that carbon credits are only sold for carbon that is already mitigated and become available after each monitoring and verification cycle. In reality, several financial constructions are possible, depending on the parties involved. To facilitate the economic feasibility of the project, credit buyers often agree with the project developer to buy a certain amount of credits in advance, by means of an Emission Reduction Purchase Agreement (ERPA). However, because there are risks involved in buying future emission reductions, the price of carbon credits in ERPA's is generally lower (Neeff *et al.* 2007). This would be especially the case for a semi-arid region, where the risk of forest fires and tree mortality is high.

Finally, the relative unattractiveness of carbon trade on the voluntary market compared to the CDM might be somewhat surprising, but this is mainly the result of the VER issuance methodology on the voluntary market that I applied. For comparative reasons, I used a methodology that has the same 'integrity' as the CDM methodology. As indicated earlier, the voluntary carbon market is rather heterogeneous and does not have clear standards yet. The results of this analysis are thus only valid for this specific VER standard.

7.2.2 Rotational woodlots

Woodfuel supply by means of rotational woodlots is highly economical in semi-arid Shinyanga. Major uncertainties are the MAI, the shadow cost of labour and the discount rate. The discount rate that was applied in this analysis is an average of the official discount rate for bank loans in Tanzania over the past years. However, a smallholder in Shinyanga is not likely to be particularly influenced by this rate, because he/she probably does not need a bank loan and the opportunity cost of capital might differ significantly form the official discount rate. In this case, an implicit discount rate might be more applicable, which reflects the willingness to invest in future benefits. This implicit discount rate can differ per farmer, depending on his/her attitude and on the resources owned. Particularly for farmers living in dry areas with high risks of agricultural failure, this implicit discount rate might be relatively high, since these farmers developed a conservative attitude towards land use change, especially when benefits are only expected in the future (Barrow 1996; Bakengesa 2007).

Ramadhani estimated a discount rate of 20% for smallholders in Tabora region who manage rotational woodlots (Ramadhani *et al.* 2001) and calculated an increase in Return on Labour of 105%, compared to a maize-fallow system. When applying a 20% discount rate in my research, the Return on Labour will increase 146% for producing fuelwood form a rotational woodlot with intercropping, compared to a maize-fallow system. The difference can be explained by the fact that Ramadhani analyzes one rotation, while I include three rotations, since the first rotation has lower benefits as subsequent rotations. Furthermore, Ramadhani determined the NPV of a rotational woodlot for fuelwood production to be 6.3 times the NPV of a maize-fallow system, compared to 5.3 times in this study. This lower value is likely to be caused by the fact that Ramadhani *et al.* use a higher MAI for a woodlot in neighbouring Tabora region.

This study is based on the results of one available experiment in Shinyanga. More data is needed on tree growth of promising tree species for agroforestry in semi-arid Shinyanga. Unfortunately, tree growth experiments are rather time consuming. Furthermore, no data could be found on wood yields of subsequent rotations of coppicing tree species. Therefore, in this study it is assumed that after the first tree harvest, the regenerating coppices have the same productivity.

The government taxes on sustainable woodfuel production from private land are extremely high and do not coincide with the government policy to combat energy poverty and deforestation. The payable fee on each unit of woodfuel produced is 80% lower for production from private land, compared to production from public forests. However, the annual government fee is equal for both public and private land and is independent of the woodlot size. This is by far the largest cost factor for small woodlots. Completely removing these tax barriers for woodfuel production from private land might give a strong incentive for smallholders to start small woodlots, not only for subsistence energy, but also for cash income by selling woodfuel. Under present policy, farmers can group up and hold one annual government license for woodfuel production. However, based on this analysis, a minimum 3.4 ha is needed to reduce the tax burden to the VAT value of 20% for fuelwood production. Such land size is relatively large, even for multiple smallholders. Furthermore, cooperation requires local organization and thus reduces accessibility of small-scale woodfuel production, especially for poorer farmers. Whilst, one of the main advantages of woodlots is the fact that establishment on a very small scale is possible. Particularly in case of charcoal production, where the market is dominated by illegal charcoal, removal of the tax barrier on sustainable produced charcoal from woodlots can lead to an increased competitiveness of this charcoal, compared to illegal charcoal and thus reduce deforestation. Although, it is unclear to what extend these government fees are issued in practise in rural areas, because of a lack of law enforcement.

In the study of Nyadzi *et al.* (2003) on rotational woodlots, the MAI of *Acacia Polyacantha* is considerably larger as the average MAI of the carbon forest. Even when corrected for the difference in spacing, the MAI in the rotational woodlot is still 2.5 times higher. This can be explained by the fact that the rotational woodlot consist of a monoculture of a selected fast-growing species, while the carbon forest consist of various local species that are not all fast-growing. For instance, *Acacia Nilotica*, a locally occurring Acacia species, has a reported MAI of only 1.2 tonne dm/ha/year (Nyadzi *et al.* 2003). Furthermore, species that grow fast in the first years might slow down considerably in later years. Finally, a rotational woodlot is established on arable land, whilst the carbon forest is established on marginal grazing land.

The benefits of both leguminous and vegetation fodder are small, however in the case of leguminous fodder only the fodder yield when harvesting the trees is accounted for and the value per tonne of leguminous fodder is assumed to be equal to vegetation fodder. In practise, valuable sources of leguminous fodder are tree pods and falling leaves, which can be accessed by cattle during the years of tree fallow. Since data on the quantity of this browse fodder could not be found and a reasonable estimate could not be made, it was not included in the analysis. Furthermore, in practise leguminous fodder is likely to have a higher value as vegetation fodder since it provides a protein-rich supplement to the daily diet (Rubanza *et al.* 2006). Thus, the benefits of leguminous fodder could significantly add to the overall benefits of the woodlot.

7.2.3 Jatropha oil production

Jatropha oil is a too expensive and too high quality energy carrier for household cooking. Its properties are better appreciated when utilized as a diesel substitute or for the production of soap, which are both highly economical. Smallholder Jatropha oil production is very labour intensive and thus the production cost thrives on cheap labour. To operate a 1 hectare plantation, 299 man-days per year are needed, of which 41% is labour for seed harvesting and 50% is labour for manual oil extraction.

Presently, Jatropha seeds are picked from already present Jatropha hedges in Shinyanga that fulfil the dual function of erosion control and cattle barrier. These seeds can be sold to Diligent, a producer of biofuels, for Tsh 100 per kg. Such seed trade can give some additional cash income to local farmers. In this case, the primary function of the Jatropha shrubs is not seed production and thus the establishment and maintenance costs of the hedges are not allocated to this. The only cost factor is labour for harvesting seeds. With a labour intensity of 40 man-days per tonne of seed, the Return on Labour is US$ 2,08 per man-day, compared to US$ 1,32 per man-day for seed production in a dedicated plantation. When assuming a yield of 2 kg per meter per year for mature shrubs (Henning 2003), a fence surrounding a 1 hectare field can produce US$ 66,40 of cash benefit per year. When applying a shadow cost of labour of US$1,43 per man-day, Jatropha seed production from dedicated plantations is found to be not economical in semi-arid Shinyanga. However, the uncertainty of the labour cost is high. When decreasing the shadow cost of labour with only US$ 0,08, a breakeven between costs and benefits is reached.

In this analysis it is assumed that under good management, the seed yield development per shrub, over the lifetime of the plantation, is equal for a plantation on arable land and a plantation on marginal land. Good management involves seedling cultivation in a nursery, annual manure application and the utilization of the produced seedcake as a fertilizer for the Jatropha shrubs. In that case, there is no extra benefit for intercropping during the first five years, since this benefit is compensated by the higher opportunity cost of land during the rest of the plantation lifetime. In this scenario, planting on marginal land is preferred so that arable land can be used for other agricultural practises.

Van Eijck assessed the economic feasibility of Jatropha plantations in areas around Arusha, which are aimed at selling seeds (2007). She indicated a significant profit potential, based on a yield estimate of 3-5 tonne seeds per ha, compared to a maximum yield of 3.2 tonne per ha in this analysis. However, optimum yields in Arusha are expected already in year 5, compared to year 9 in semi-arid Shinyanga and the market price around Arusha is higher compared to Shinyanga, because of less transportation costs.

Both Henning (2004) and Matchmaker (2007) determined the economic feasibility of Jatropha soap production and both indicate high profit margins, as in this analysis. However, Jatropha soap is presently a niche market. With an increasing market for this soap, the farm-gate price is likely to decrease because of competition effects.

A major benefit of cooking on Jatropha oil is the health benefit because of the absence of harmful smoke. However this benefit is not included in this analysis, since it could not be expressed in a monetary benefit. On the other hand, significant health improvement can also be realized when cooking on fuelwood using a burnt brick stove and a chimney.

Because of the rapidly increasing oil prices, diesel prices in Tanzania are skyrocketing. In remote areas the cost of diesel is further increased by high transport costs. Jatropha oil as a diesel blend in local engines, tractors for instance, has market potential, since its production cost is 49% of the market price of diesel. However, this is 59% when fuel taxes are excluded. Furthermore, when Jatropha oil is grown for commercial purposes, 20% VAT has to be added to the production cost. To scale up a local market for Jatropha oil as a diesel substitute, local production should be scaled up. Therefore, more cost-efficient oil production is needed. The most straightforward improvement would be oil extraction by means of a mechanic oil expeller instead of a manual ram press. Such an expeller has a labour intensity of 3.6 man-days per tonne of seed (van Eijck 2007a), compared to 48 man-days per tonne seed when using a manual ram press (Henning 2003), which comes down to an annual saving in labour costs of US$ 208 per hectare, or US$ 6,73 per GJ. Furthermore, the oil extraction efficiency is 75-80%, compared to 60-65% for a ram press (Henning 2003). In Tanzania a mechanic oil expeller costs around US$ 2.000, excluding fuel and maintenance costs (Bagani 2008). This is unlikely to be affordable for smallholders. Alternatively, cooperatives could be promoted, in which farmers who grow Jatropha participate. Such cooperatives could invest in an oil expeller using a bank loan, or by donor funding. Remaining problems are the facts that because of its high viscosity, such oil can only be used as a diesel blend of up to 30% (Pramatik 2003) or as a fuel in engines adapted for plant oil. Furthermore, Jatropha oil can only be stored for a limited time because of natural degradation. Nevertheless, rural electrification using a generator powered by an adapted diesel engine fuelled by raw Jatropha oil seems a promising alternative for diesel fuelled electrification.

An important drawback is the large cost of generator adaptation for running on Jatropha oil. The production cost of electricity is determined to be US$ 0,60 per kWh, compared to US$ 0,79 per kWh when run on conventional diesel. US$ 0,60 per kWh seems relatively expensive compared to the rate of about US$ 0,10 per kWh for a TANESCO rural electrification project, although the latter is subsidized. Furthermore, Ilskog reported an electricity price of US$$_{2007}$ 0,54 per kWh for a private off-grid electrification project to be still economical (Ilskog *et al.* 2005). However, such private electrification will only be accessible for the richest in a rural community. The indirect benefit of rural electrification is hard to estimate, but it is certainly more than only the social function of lighting. Lighting extends the day and allows economic activities at night. Furthermore, electricity can be used to run machinery and small enterprises that can realize a higher return on labour and create employment (Maleko 2005). Jatropha oil as a fuel for local electricity generation and machinery propulsion is already practised in Tanzania, by means of so-called ‘multi-functional platforms’ (TaTEDO 2008), however, an economic analysis of this project is not available. Del Greco *et al.* estimated the costs of providing electricity for a hospital in Tanzania by using a generator running on locally produced Jatropha oil (2005). They estimated an oil production cost of US$$_{2007}$ 0,60 per litre. This estimate was based on a plantation size of 4 ha and the use of a mechanical oil expeller instead of a manual ram press, which explains the lower cost compared to this study.

From a government perspective, it might be desirable to scale-up Jatropha production even more, in order to produce biofuel for the national transport sector and decrease the foreign exchange expenditures on oil import. However, for this purpose the produced Jatropha oil needs to be further processed by means of transesterification, which is a capital intensive process. Such facilities demand more centralization of oil production, in which case it seems more cost-efficient to combine oil extraction and transesterification in single plants, so that farmers will only supply seeds. On the other hand, it is questionable whether smallholders should be encouraged to invest their labour capacity in Jatropha seed production, instead of food production when taking into account that the profit margin of Jatropha seed production is small, if not subsidized by the government. Most likely, Jatropha will be just another cash crop, next to tobacco or cotton.

7.2.4 Methodology

As a baseline for this analysis, the economics of maize cultivation was analyzed, based on a maize-fallow system of two years maize cultivation, followed by a three years fallow period. This was translated to the economic parameters of the opportunity cost of land and the return on labour. However, to obtain a more complete picture, various agricultural systems should be analyzed. Furthermore, the opportunity cost of grazing land and agricultural land should be determined more accurately by carrying out a more extensive survey. Because of a lack of available time, the baseline assessment was limited for this study.

The shadow cost of labour is a large uncertainty in cost/benefit analysis of smallholder agricultural systems, because of the absence of a standard wage for agricultural labour, caused by the reciprocal nature of the smallholder economy. Furthermore, the shadow cost of labour is likely to depend on the season, since agriculture in Tanzania is highly seasonal. In the sowing and harvesting season, the shadow cost of labour is likely to increase strongly because labour demand is high, while during the dry season, the shadow cost might be much lower. Furthermore, the shadow cost of labour differs between men, women and children. However, to what extend it may fluctuate is not known and literature could not be found in which the labour costs were varied per season. Thus a constant average shadow cost was assumed in this research. In practise, a higher labour demand during the agricultural labour demand peak, can lead to a significant increase of the biomass energy production cost.

In this research, both the NPV and the Return on labour were assessed. This was decided because the NPV only indicates the added value that can be obtained per hectare. In Shinyanga, farmers own relatively large areas of land and are often more constrained by their labour capacity as by their land ownership. Therefore, it makes sense to include the Return on labour in this analysis, which indicates the maximum added value per unit of labour. Added to this, the NPV can be positive because added value is created on a hectare of land, while the Return on labour is below the baseline of the maize-fallow system, because this added value is highly labour intensive. Both the NPV and the Return on labour are economic constructions that allow comparison of alternatives. The NPV basically indicates the cash that the farmer would accept today, instead of all the net benefits over the lifetime of the projects. The NPV can only be valued, compared to a baseline. In this research, the NPV of the baseline maize-fallow system was set to zero, though this is just a matter of definition. The Return on labour is the discounted average value of labour benefit over the lifetime of the project. It does not indicate the real wage that is earned per day of work. This also applies for the Cost of energy, which is the average discounted production cost over the whole project lifetime. However, in theory the discount rate functions as a correction factor for the time gap between costs and benefits.

The rather unusual parameter of the Cost of utilized heat was introduced to better indicate and compare the real energy cost of household cooking. The main reasons for this are the large differences in cooking efficiency and investment costs between various cooking methods, although the investment costs per GJ of heat produced were found to be insignificant for all stoves. This approach revealed the high indirect cost of fuelwood combustion on a 3-stone pit, compared to other energy sources like charcoal, which is generally regarded as more expensive. Furthermore, the overall efficiency of charcoal utilization is hardly lower as fuelwood consumption because of the higher cooking efficiency of charcoal stoves. However, many people in rural areas are constraint by a lack of cash to invest in higher quality energy carriers and stoves and are thus bound to collect ‘free’ fuelwood.

7.2.5 Reflection on semi-arid Shinyanga

Energy poverty is worse in drier areas, mainly because there is less woody vegetation cover. For this reason, a semi-arid region was chosen for this case study. Shinyanga region is dominated by the Sukuma, an agro-pastoralist tribe whose most dominant activity is livestock keeping. The number of livestock owned is a status symbol and is preferred above the quality of livestock. One of the downsides of the huge numbers of livestock that are present in Shinyanga, is increasing land degradation. This is blocking natural regeneration of woodlands and increases fuelwood shortage, while fuelwood harvesting itself is hardly responsible for deforestation. On the demand side, fuelwood is still burned at very low efficiencies. While simple techniques are available to increase the cooking efficiency, these are hardly practised, even though women have to take large efforts in order to collect sufficient fuelwood. Furthermore, agricultural production is low. Farmers in Shinyanga cultivate relatively large areas of land, but insufficient management causes low overall yields. This low labour productivity is the common problem for these three socio-economic factors, livestock, agriculture and energy. A low return on labour prevents people from investing in the future. At the same time, the population growth rate is one of the highest in the world and is outgrowing the increase in food production. For sustainable development it is important that productivity is increased per unit of labour invested and per unit of land used, which is exactly the focus of agroforestry. By combining crop cultivation and tree growing, both grazing, food production and energy demand are addressed, which results in a higher return on labour. A high return on labour can create the resources needed for farmers to invest in better quality seeds, fertilizers or weeding labour, improved cooking stoves, etc, in order to increase productivity even more. In practise however, cultural boundaries are blocking the dissemination of these technologies. A lack of clear land ownership, gender inequality and the high social value of cattle are the main constraints.

A major cost that is not included in this cost/benefit analysis is the cost of knowledge sharing. Local communities need to be informed about better agricultural practises, agroforestry and improved cooking stoves. Lack of funds and a lack of infrastructure hamper dissemination of knowledge amongst rural communities. This problem is also manifested at the demand side: Farmers often do not have knowledge of regional market prices and market opportunities, resulting in inadequate negotiation power towards transporters.

The calculated Return on labour and the Cost of energy are assumed to be constant over the project lifetime, even as all input data. In reality, of course, this is unlikely to be the case. The economy of Tanzania is growing rapidly, even as the population and thus it can be expected that these factors will not be constant over a time span of 20-30 years. On the other hand, this economic growth is mainly taking place in large urban areas like Dar es Salaam and Arusha. At the moment, the government of Tanzania is constructing a tarmac road which will connect the cities of Mbeya and Shinyanga with Dodoma and Dar es Salaam. This road is likely to bring considerable economic improvement to the region, since it will significantly lower transport costs and increase market access. However, remote rural areas are hardly affected by these developments, since these areas seriously lack market access, which prevents them from profiting from the welfare increase. This lack of market access constrains the economic feasibility of commercial production of poles, charcoal and Jatropha products. Though, the fact that multiple products can be produced from a rotational woodlot and from a Jatropha plantation is a benefit, since multiple products mean multiple markets that can be addressed. This increases the probability of market access in an area, reduces risks and secures farmers of an income.

When welfare increases, the shadow cost of fuelwood collecting will increase too, so that higher quality energy carriers become more attractive. Furthermore, more cash becomes available for purchasing higher quality fuel. Jatropha oil produced in more centralized plantations might then become an attractive alternative for *hambo hambo*, the large middle-class of the society in Shinyanga. However, when welfare increases, the labour cost for Jatropha oil production will increase too.

A main advantage of rotational woodlots, or agroforestry in general, is the fact that one area of land is used for multiple products. Thereby not only the NPV per hectare is maximized, but also the labour productivity, because labour can be combined for both trees and crops and because crop yields may increase significantly. Furthermore, wood can be harvested and processed during the dry season, which means that labour can be spread more over the year compared to sole crop production, where all labour is concentrated in the wet season. In this way, a farmer is less constrained by his/her labour capacity for making a profit. This is a large benefit compared to Jatropha cultivation, where intercropping cannot be practised permanently, so that labour competition between Jatropha and food crop production may occur. Furthermore, Jatropha seeds need to be harvested mainly during the wet season. Another advantage of multiple land use in rotational woodlots is risk mitigation. Smallholders increase their income portfolio and can fall back on trees in years of crop failure, so that their resilience towards drought or other shocks is increased (Morris *et al.* 2002).

However, to start a woodlot, excess land is needed on top of the land needed for subsistence cropping. As a result, rotational woodlots are most likely to be implemented by *Hambo hambo* and *Nsabi*, the wealthier groups in Shinyanga. For poor farmers, the need to rent land for rotational woodlots is a significant barrier since the benefits cannot be obtained in the same season (Msuya *et al.* 2006). Jatropha on the contrary, is claimed to grow on marginal land so that no land rent costs are involved. The fact that Jatropha can grow on marginal land is often claimed as a large benefit, for the reason that this avoids competition with food production. However, on general land a Jatropha plantation competes with livestock grazing, which will increase the grazing pressure elsewhere. Furthermore, it is questionable whether arable land is the largest factor of competition with food production in Shinyanga, since land is readily available. Competition with labour capacity for food production might be a larger constraint, since Jatropha oil production is very labour intensive.

8. Conclusions and recommendations

Four research questions were formulated for this research. These questions can now be answered:

A. *What is the economic feasibility of the three small-scale biomass energy supply systems in East Shinyanga?*

Based on an estimated mean annual biomass increment of 2 tonne dm/ha/year, local fuelwood supply by means of a carbon forestry project is not economically feasible for a project developer/investor in East Shinyanga. The estimated mean annual biomass increment is too low while the cost of fire management is relatively high. As a result, the management costs per hectare of planted woodland are larger as the carbon benefits per hectare. However, the uncertainty in the input parameters is large. Furthermore, it does not include the total benefits in terms of forest environmental services for the local community are significant, although these could not be quantified accurately in this research.

Smallholder Jatropha oil production as an alternative fuel for household cooking is not economically attractive. Based on the input parameters, the cost of utilized heat for household cooking is US $45 per GJ_H, compared to US$ 27,89 per GJ_H for combusting fuelwood on a 3-stone pit with an efficiency of 7%. When this low fuelwood cooking efficiency would be increased by means of an improved cooking stove, the cost of utilized heat even decreases to US$ 7,27 per GJ_H. Furthermore, considerable investments are needed for Jatropha oil production. At an estimated maximum annual seed yield of 2 kg per shrub, about 31 GJ/ha of Jatropha oil can be produced annually. In semi-arid Shinyanga, the production cost of Jatropha oil by manual pressing is determined to be US$ 0,73 per litre on a monoculture plantation, which is 49% of the diesel market price in Shinyanga. Therefore, Jatropha oil can be an attractive diesel substitute, both as a blend or as a fuel in adapted engines. Furthermore, it can be used as a fuel in an adapted generator for the production of off-grid electricity. From a 1 hectare Jatropha plantation, 2.320 kWh of electricity can be produced annually, at a cost of US$ 0,60 per kWh, compared to US$ 0,79 per kWh when producing this amount of electricity by using a diesel-fired generator. Jatropha oil is further highly economical as an ingredient for Jatropha soap production. However, at this moment, this is still a niche market.

Rotational woodlots have great potential to increase the income of rural farmers and provide relatively low-cost sustainable biomass energy to rural households. When growing *Acacia Polyacantha,* a wood production of about 70 tonne dm per hectare after 7 years of growth can be realized. The production cost of fuelwood is US$0,53 per GJ, which is Tsh 163 per headload in local units, compared to a present market price of Tsh 600 per headload. Per hectare, 162 GJ of energy is produced annually. Charcoal can be produced at a cost of US$ 1,71 per GJ, or Tsh 1.914 per bag, compared to a farm-gate price of Tsh 5.000 per bag. Under best practise kiln efficiency, the utilized heat produced per hectare of woodlot is about equal for fuelwood and charcoal, since the energy loss of the carbonization process when producing charcoal is compensated by the higher efficiency of charcoal cooking stoves. Added value per hectare of rotational woodlot can be maximized by selling the stem wood as timber or poles, in case a sufficient market is available. The maximum Net Present Value is found to be US$ 1.165 per hectare for the production of poles and charcoal when applying maize intercropping. The maximum Return on labour is about US$ 7 per man-day for producing poles and fuelwood in a monoculture, compared to US$ 1,88 per man-day in the baseline maize-fallow system. Therefore, a farmer who is constrained by land could better produce charcoal from an intercropped woodlot, while a farmer who is constrained by labour could better produce fuelwood from a monoculture woodlot. Intercropping of maize adds significant value to the rotational woodlot and accounts for 17% of the annual benefits per hectare obtained. The average annual maize production per hectare is found to be only slightly lower in a rotational woodlot, compared to a maize-fallow system of 2 years maize and 3 years fallow.

B. *Which factors have the largest influence on the economic feasibility of these systems?*

For all three systems, labour is the largest cost factor. In case of carbon forestry, land workers are paid the Tanzanian minimum wage rate of US$ 3,06 per man-day. The shadow cost of labour for smallholder Jatropha cultivation or rotational woodlots is hard to determine. Partly based on the economics of maize cultivation in Shinyanga and partly based on expert estimates, the shadow cost of labour was determined to be US$ 1,43, or Tsh 1.722, per man-day. The Net Present Value and the Cost of energy are highly sensitive towards variations in the shadow cost of labour, especially in the case of labour intensive Jatropha oil production. For the total production process, about 10 man-days per GJ are needed when using a hand press, compared to about 0.25 man-days per GJ in a rotational woodlot, which is 29 minutes per headload of fuelwood. However, Jatropha yields a higher quality fuel compared to woodfuel. The mean annual biomass increment has a great impact on the economic feasibility in the case of carbon forestry and rotational woodlots. The impact of the annual Jatropha seed yield on the production cost of Jatropha oil is less decisive, since 91% of the labour costs are independent of the per hectare seed yield and labour costs make up 71% of the total discounted costs of Jatropha oil production. Major obstacles for the profitability of rotational woodlots are the annual government fee and the payable fees on fuelwood and charcoal production. When a farmer would produce commercial woodfuel from a 1 hectare monoculture woodlot, the high Net Present Value is completely removed by this tax burden.

C. *What are the potential socio-economic impacts of these biomass energy supply systems on rural smallholders?*

Similarly to the local practise of *Ngitili*, a local community involved in carbon forestry will experience large benefits from forest products and soil quality improvement. These benefits could not be valued in monetary terms, although it might be an incentive for donor organizations to engage in carbon forestry even though it is not economically feasible from an investor's perspective. However, the decision to establish a carbon forest is not likely to be made by smallholders and it is thus more a top-down approach, compared to woodlots or Jatropha oil production, were each smallholder can decide to start a woodlot or cultivate Jatropha. The benefit of soil quality improvement also applies for rotational woodlots and Jatropha cultivation, however on a much smaller scale per capita. Because labour is added compared to the baseline, potential employment is created for all systems. Even though, a lack of labour availability during the agricultural season can be an obstacle for implementation. In case of rotational woodlots, wood harvesting is carried out during the agricultural off-season, so that labour competition with food production can be avoided. Utilizing Jatropha oil to fire a generator for local electrification strongly reduces the cost per kWh compared to using conventional diesel. Apart from the potential local economic benefits of Jatropha oil production, access to electricity strongly increases the quality of life and creates opportunities for various kinds of economic activities. For all systems, livelihood resilience against risks is increased by creating access to, or producing multiple products, that can supply multiple markets.

D. Which of these systems is preferable from a socio-economic point of view?

These systems can all be favourable, depending on the specific function that is aimed at.

From a smallholder perspective, rotational woodlots are preferable for producing household energy and increasing income. It has the lowest investment costs, the highest energy production per hectare, the lowest cost of energy, the highest return on labour and the highest Net Present Value per hectare of land. Furthermore, when intercropping is applied properly, competition with food production can be avoided. The socio-economic benefits of carbon forestry per area of land are likely to be significant and from a smallholder perspective, these benefits come without any labour invested in establishment. However, the socio-economic benefits could not be valuated properly in monetary terms and thus a monetary comparison on this part is not possible. Jatropha oil is highly profitable as diesel substitute for local electrification projects or as an ingredient for soap production, although the latter is still a niche market.

From a government perspective, the positive socio-economic and ecological impacts of forestation for carbon mitigation in semi-arid Shinyanga might compensate for the gap between financial costs and benefits caused by the low growth increment. When taxes are lifted, rotational woodlots have great potential to alleviate the household energy scarcity in semi-arid Shinyanga by supplying low-cost fuelwood and charcoal. Moreover, Jatropha oil is a cost-effective alternative for diesel in rural areas, both as a transportation fuel and as a generator fuel for local electrification projects, especially now the oil prices are rapidly increasing.

8.1 Recommendations

- The government taxes on sustainable woodfuel production from smallholder land are extremely high and do not coincide with the government policy to combat energy poverty and deforestation. Completely removing these tax barriers for fuelwood and charcoal production from farmland might give a strong incentive for smallholders to start woodlots, not only for subsistence energy, but also for cash income by selling woodfuel. Particularly in case of charcoal production, which is a market dominated by illegal charcoal, removal of the tax barrier on sustainable produced charcoal from woodlots will lead to an increased competitiveness of this charcoal, compared to illegal charcoal and hence reduce deforestation.
- To successfully promote and scale-up rotational woodlots, increased dissemination of knowledge on rotational woodlot establishment and management is needed amongst farmers. Furthermore, tree seedling distribution should be scaled-up.
- On the demand side, the cost of utilized heat for cooking can be strongly reduced by the promotion of improved cooking stoves in rural areas.
- Research on tree performance, as carried out by the NACRAF institute in Shinyanga, should be enhanced and if possible scaled-up.
- Research is needed on the local socio-economic benefits of carbon forestry. Research is needed on the economic benefits of vegetation fodder and leguminous fodder.
- Research is needed on the seed yield of Jatropha *curcas L.* in semi-arid Shinyanga under different soil qualities.
- To better determine the economic feasibility, research is needed on the labour intensity of Jatropha oil production.

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APPENDICES

APPENDIX A: Cooking stove technology

As an alternative for cooking on a three stone pit, various improved cooking stoves are available. The stoves that were used in this analysis are listed below. All information on fuelwood and charcoal stoves was retrieved from Pesambili at TaTEDO in Dar es Salaam (2007).

Mud stove

Figure 49: Example of a mud stove.

The construction of mud stoves is site specific and depends on the soil quality, which is good in Shinyanga. The stove is build from a mixture of mud, grass and straw. Under good management a lifetime of 3 years is possible, but this includes daily maintenance by smearing the stove with a mixture of soil, water and ash, to prevent it from cracking. Still, repair will be needed now and then. Without this maintenance, the lifetime is 2–3 months. The efficiency of mud stoves, whatever model, is about 20–25%. The stove can be made for free when materials are available. The cost of a technician to build one is about Tsh 2.000 – 3.000. The picture shows a high quality mud stove, built by a woman who promotes the utilization of improved cooking stoves among other women.

Burnt Brick stove

Figure 50: Example of a large bunt brick stove, including a chimney.

This is a permanent stove which is constructed of two layers of cemented bricks. The inner wall is surrounding the combustion chamber. This wall is made of special high temperature resistant bricks, however these bricks cost US$2-2,50 per piece. A burnt brick stove costs Tsh 40.000 – 80.000, for single households, depending on the size. However, the price can go up to Tsh 1.000.000 for large stoves used in institutes, as shown on the picture. A chimney to remove the smoke is well possible. The efficiency is about 28-30%.

Ceramic liner charcoal stove

Figure 51: A Ceramic double liner charcoal stove.

A traditional, simple, metal charcoal stove has an efficiency of 15-18%. Improved charcoal stoves vary in efficiency between 28-45%. Ceramic liner stoves have a special template where the charcoal is resting. This template is made out of vermiculite, which is special cement that is hardened in a furnace and has a poor thermal conductivity. This ceramic liner is basically the improvement compared to normal cooking stoves. A single liner stove has an efficiency of 28%, at a cost of US$6, a double liner stove has an efficiency of 45%, at a cost of US$ 8. The lifetime of the liner is 18 months, after which it has to be replaced. The cost for a new liner is Tsh 1.000-2.000. A problem is thus that a supply of new liners is needed. The metal construction has a lifetime of 3 years. The shape of the stove is tapered to reflect the heat towards the pan. The picture shows a double ceramic liner stove.

BSH Plant oil stove PROTOS

Figure 52: The PROTOS plant oil cooking stove. Source: (BHS 2008).

Kerosene is widely utilized as a cooking fuel in urban areas in Tanzania, by using a conventional wick stove. However, plant oil, like Jatropha oil, has a too high viscosity for utilization in a wick stove. Using Jatropha oil would burn the wick and would lead to harmful emissions, because the oil is burned at a too low temperature. Bosch Siemens Hausgeräte GmbH developed a plant oil cooking stove for household cooking in developing countries, named PROTOS, based on a different principle.

The problem of high viscosity of plant oil is solved by pressurizing the oil, after which the oil is vaporized by heating it with the cooking flame. The gas is emitted from a nozzle and is burned at a very high temperature, to assure complete combustion (BHS 2008). The efficiency of this stove is 45% and the estimated cost is 40 Euro (Kratzeisen *et al.* 2007). Besides the relatively high price, a disadvantage is the high maintenance requirement.

APPENDIX B: Visit to Ruvu Fuelwood Pilot Project (RFPP)

Date:	3 October 2007
Contacts:	Mr. Liana, Management Assistant RFPP Mr. Mndolwa, Research Director at Tanzania Forestry Institute (TAFORI) office in RFPP

Mr. Liana
The dry woodlands around Dar es Salaam consist of miombo and acacia species. The mean annual rainfall is 1000 mm, but this can vary significantly over the years. The woodlands are heavily degraded because of the enormous demand for charcoal from Dar es Salaam. The Ruvu Forest Reserve used to be a productive forest reserve, which means that previously, local people were allowed to obtain their fuelwood from the forests and some people were given a permit for commercial charcoal production. The system was law-enforced by police control. However, this did not work because it was hard to check who had a license and who not. People with a license were often bribed by others to stay next to the kiln. Another problem were the low penalties of Tsh 30.000. The system was not working and land degradation continued at an alarming rate. Ruvu can be divided in a northern and a southern part. In North Ruvu most forest is gone and what remains is bush and grassland.

In 1996, the government decided to close most of the forest completely for people (59.000 ha) and reserve 8.000 ha for charcoal production. Local village households were assigned 3 hectare of land per household, which they could clear to start rotational woodlots for charcoal production. Clearing of land was a one-time extra income, because they could produce a lot a charcoal. Nowadays 670 households are participating. Households not only were given land but also free seedlings. They were educated about good tree management and were explained to let the trees grow for 10 years. Most farmers started to intercrop cassava and maize. People were also encouraged to protect indigenous species like African Blackwood (*Mpingo*) on their fields. However, in general forest regeneration and management and biodiversity conservation is still a government task. The 3 hectare of land that the farmers received is often only partially used. The reason is lack of manpower to take care of so much land.

Local village households mainly practise subsistence farming. For their income, they depend for 90% on the forests. The main income source is charcoal production, however hunting, bee-keeping and mushroom collecting also add to the annual income. On the one hand, farmers were glad that they got new land, because the land they own in the village is heavily degraded and is not productive anymore. Local farmers explained that they produce much more from intercropping on the plots than what they produce around the village. However, people were also hesitating because they did not trust the government. They thought that the government was tricking them and did not believe the land was really their property. Furthermore, people are not familiar with tree planting. They do not see how they can make money, because the profits come only after a period of 10 years. People had to be trained to plant trees and now they also realize the value of it.

However, the main problem is the fact that farmers started to cut their trees massively to sell them as poles after only 3 years of growing. Only the tree branches were converted to charcoal. This is because the market price of poles is higher as the market price of charcoal and people prefer quick money since they are poor and are always lacking income. Farmers were arguing that since it is their land, they can use it in the way they prefer. In this sense, the project is failing because limited charcoal is produced, on the other hand, household income of participating households was strongly increased and nowadays local farmers are more aware of tree planting. Furthermore, trees regenerated quickly from coppice re-growth after being cut for poles.

Figure 53: Illegal charcoal maker preparing a kiln in the Ruvu Forest Reserve, close to Dar es Salaam.

Another problem is the heavy exploitation of the forest by illegal charcoal makers. Most of them are immigrants that are attracted to the forest because of the high charcoal price in Dar es Salaam. However, also village people visit the forest illegally to produce charcoal. Because charcoal makers are afraid of being caught, they quickly cut big trees, but only convert the branches to charcoal, because they don't have much time. In this way the rate of deforestation is even increased. There is hardly any law enforcement so illegal charcoal makers are not afraid of being caught. We saw several illegal charcoal makers during our field trip. Most would run away, but some would not even care. Illegal charcoal makers also do their work at night, making it very hard to catch them. The rapid deforestation caused by this practise is alarming, though these illegal charcoal makers are very poor. For them this is their only way of obtaining an income and they are totally dependent on this. The real problem is the enormous charcoal demand coming from Dar es Salaam.

Mr. Mndolwa

All woodlot activities are carried out by the farmer families alone. This explains why they cultivate less land than they own. However, wood harvesting has to be done at once. The farmer has to negotiate a wage with other farmers to help him. He also has to negotiate a price with the charcoal trader in advance. Thinning is only needed for timber production to create large diameter stems and pruning is only needed to create long stems. For charcoal production this is not necessary. The nursing area of the RFPP is small, but nursing is expensive since a lot of water is needed. The seedlings have to be watered twice a day.

Miombo woodlands regenerate quickly out of coppices and root suckers. Totally degraded woodlands can be restored in 3 years if left untouched. Regeneration is always practiced and planting is therefore not needed. A CDM project in the area would not be feasible because Miombo would regenerate everywhere in the baseline. Furthermore, it is very hard to plant Miombo trees in these areas since fires occur every year. To prevent fires, the land has to be weeded 4-5 times per year. Furthermore, fire lines should be applied. Thus, planting is possible but not practised. Another constraint is the fact that de charcoal demand from Dar es Salaam is so big that illegal logging would be hard to prevent and protecting the forest would become very expensive. However, maybe when people realize the value of the trees, they are willing to adopt better protection.

APPENDIX C: Optimal rotation periods for rotational woodlots

In theory, in a rotational woodlot, the wood yield over successive rotations can be maximized by harvesting at the point were the Annual biomass increment is equal to the Mean annual biomass increment (Malimbwi 2007), as shown in Figure 54:

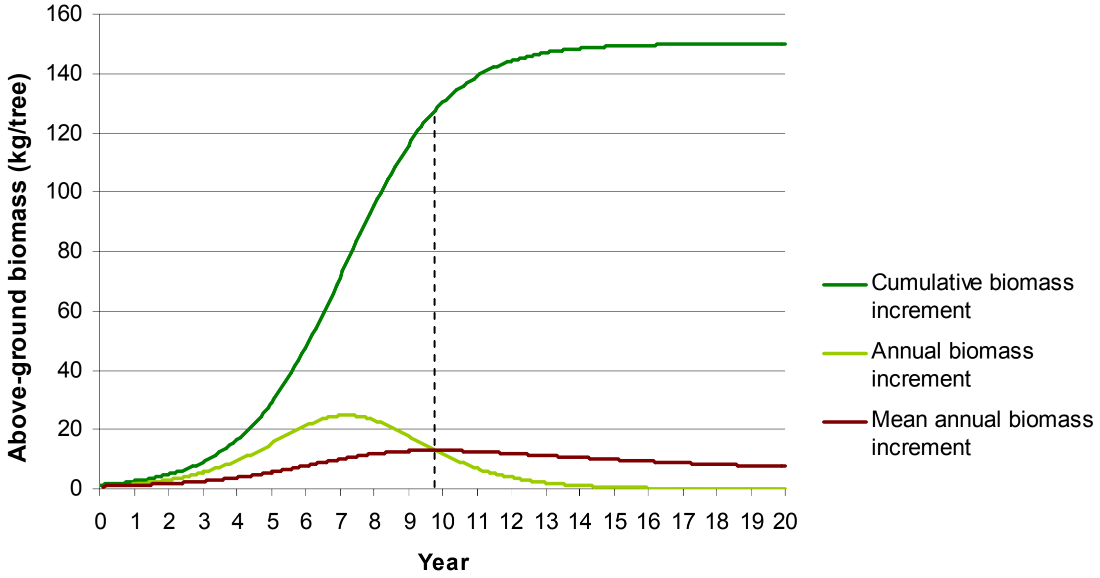

Figure 54: Example of optimal rotation period for maximum wood yield over successive rotations.

However, when expressing the wood yield in monetary terms and applying a 20% discount rate over the monetary benefits of wood harvest, the optimal rotation period is significantly decreased, as shown in Figure 55:

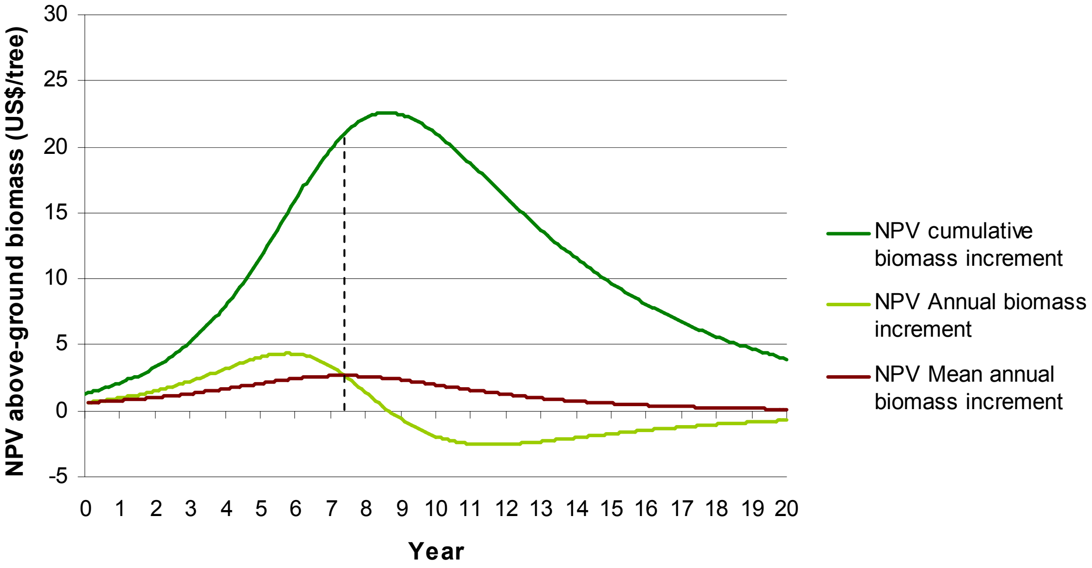

Figure 55: Example of optimal rotation period for maximum financial benefits over successive rotations, when applying a 20% discount rate. 1 kg of biomass is assumed to have a value of US$ 1.

In case of smallholder rotational woodlots, this discount rate may indicate the time preference of smallholders for making a profit.

APPENDIX D: Field survey in Shinyanga Rural

A small survey was carried out in villages around Shinyanga urban, on November 7th 2007. The results are listed below:

Village	**Samuye**	**Mwamala**	**Usanda**	**Old Shinyanga**	**REMARKS**
Location	12 km from Shinyanga at highway	close to Samuye, but a few km from highway	25 km from Shinyanga at highway	10 km from Shinyanga over a dirt road	
ENERGY					
Price ox-cart of fuelwood (Tsh)	10.000	7.000	10.000		
Price headload of fuelwood (Tsh)	500	not common	500	500 - 700	Depending on wet or dry season
Weight headload of fuelwood (kg)	30		15	13	Samuye probable overrated
Household fuelwood consumption	2 headloads/week	4 ox-carts/year	3,5 headloads/week	7 headloads/week	1 ox-cart is approx. 20 headloads
Households size	7 persons	7 persons	7 persons	9.5 persons	
Wood surplus/deficit	Deficit	Deficit	Deficit	Deficit	
Fuelwood consumption if surplus	3 headloads/week	8 ox-carts/year	7 headloads/week	14 headloads/week	
Crop residues use as a fuel	Occasionally	Occasionally	Maize cobs after harvest		
Price crop residues (Tsh)	free	free	free		
Cow dung used as fuel	not common	never	not common		
Dominant cooking method	3-stone	3-stone	3-stone	3-stone	
Charcoal price farm-gate (Tsh)	9.000 – 12.000	7500	6000 - 7000	7500 - 8000	Illegal bicycle transporter: Tsh 5.000 at 25 km from Shinyanga
AGRICULTURE					
Farm-gate price maize (Tsh/debe)	6.000	5..000	5.500		1 debe (bag) is approx. 18 kg
Price of cow manure per ox-cart (Tsh)	10.000	price not fixed	2.000 – 3.000		
Price of fodder grass (Tsh)	2000/sack	not common	500/bundle		
Land rent agriculture (Tsh/acre/season)	20.000	10.000	20.000		
Land rent grazing land (Tsh/ha/season)	20.000	19.500	18.300		
OTHER					
Price of poles (Tsh)	1.000 – 3.000	2.000	2.000 – 3.000		Mwamala: 3 x Ø0,15 mtr.
Price of kerosene (Tsh/litre)	1.500	1.500	1.800		
Price of diesel (Tsh/litre)	1.525	1.525	1.800		

Table 24: Results of a survey in four villages around Shinyanga Urban.

Samuye village

Samuye village is located at the Shinyanga–Mwanza highway at about 10 km from Shinyanga. One household was interviewed. The woman does not collect fuelwood because there is no forest to collect from and she does not have trees on her homestead. She can collect some branches from a relative's *Ngitili* but that is not enough. Instead, she has to purchase fuelwood for Tsh 500 per headload. The woman does not use an improved stove because she does not know how to build one. She would like to plant trees, but she has no seedlings. Therefore, she has requested seedlings from the government. She would prefer *Azadracta Indica*. The woman is using about 2 headloads of fuelwood per week, which she experiences as a fuelwood deficit. If there would be plenty of wood she estimates to use 3 headloads per week. She also indicates that fuelwood is not so much a problem. It is rather cheap, compared to other expenditures. The farmers in the village are also interested in planting Jatropha, but they have no seeds.

Mwamala village

Mwamala village is situated a few kilometres off the Shinyanga–Mwanza highway, at about 20 km from Shinyanga. One household was interviewed. The farmer is the son of the previous village chief. He is quite rich and owns 120 acre of land of which he uses 100 acre for *Ngitili* and woodlots. According to Rubanza, he is one of the progressive, early adopting farmers. The average household in the village has 1 acre of woodlots and 10 acres of total land. Most people in the village depend on wood from their own farm.

Cow dung is not used for cooking. It is only used in areas with very little trees, like Meatu. This is the same for crop residues. It is not used as a fuel in the entire region. The family obtains wood from their own woodlot, since the nearest natural forest is 8 km from the farm, which is too far to walk. Even though the farmer owns 100 acres of *Ngitili*, he indicates to face a woodfuel deficit. The household consumption is 1 ox-cart of fuelwood, every 3 months. If there would be no wood deficit they would use 2 times as much as now. Tree species preferred for fuelwood are *Acacia Nilotica* and *Senna Siamea*. The household stopped having campfires to minimize their fuelwood consumption. They do not buy wood, but they do sell. For them it is better to earn cash income than to have more wood. The household uses a 3-stone cooking stove. They do not improve the cooking efficiency, because they do not know how to build an improved stove. The seedlings for their woodlot were provided by the district, as part of a forestation program. They do not intercrop on their woodlots because they are afraid for competition effects.

Usanda village

Usanda village is at the Shinyanga–Mwanza highway, about 25 km from Shinyanga. Because we arrived at the end of the day, we had the chance to question a large group of people at the public gathering place, including some women.

Fuelwood is obtained both from private woodlots, *Ngitili* and general land. The general land is about 4 km from the village. It takes about 1 hour to walk over there and 1 our return. Collecting takes about 4 hours in total. This means that per headload, 6 hours are needed. A headload is sold for Tsh 500 in the village. Most people buy fuelwood from woodlots, or from women that have a business in collecting fuelwood from the general land. Everybody experiences a fuelwood deficit. On average, they use one headload per household, every 2 days, but they would use one headload per day if possible. Only a few people use improved cooking stoves.

Old Shinyanga

Old Shinyanga is located at approximately 10 km from Shinyanga. The interviewed woman is living in the village centre. She indicated that her energy consumption is different from people living outside the village, since she consumes more charcoal. Charcoal is more expensive, but it has some advantages: Fuelwood is making the pans dirty and when using charcoal, one does not continuously have to watch the stove when cooking. Charcoal is used in the village, but it is much more expensive, about Tsh 1.500 per debe, or Tsh 7.500–8.000 per bag. The woman uses fuelwood for cooking drinking water. She is cooking 30 litres of drinking water for her household, every 2–3 days, for which she uses one headload. For cooking of meals (3x per day), she is using one bag of charcoal per week. If she has to economize on energy expenditures, she would use 5 headloads of fuelwood and 3 debe of charcoal per week. In case of more economizing, she would use 7 headloads per week and no charcoal. Ideally, she would use only charcoal.

A headload of fuelwood costs Tsh 500 at this moment, however during the wet season this increases to Tsh 700. This is regardless of the tree species. We weighted a sample headload to be 13 kg. However, the weight is very much dependent on the tree species used. People that have to collect fuelwood from the nearest forest take 5–6 hours to do so. They have to start walking at 6 AM to arrive there early so that they can avoid being caught, since it is illegal to collect fuelwood from the natural forest. The forest is 10 km from the village. Walking takes most of the time. Women that collect fuelwood use it for own consumption. About 70% of the people in the area have their own woodlots or *Ngitili*. Furthermore, there are dealers that sell wood. An average household consumes 1 headload per day, which is enough for cooking 3 times. There is a fuelwood deficit in the area. If there would be plenty of wood, people would use double their wood consumption. This happens actually in villages where there is more wood available. The given fuelwood consumption is for a family size of about 9-10 people. Mainly acacia species are used for fuelwood.

APPENDIX E: Maize production in East Shinyanga

Table 25 shows the average maize production in Shinyanga over the period 1997–2003:

Year of harvesting	Land under maize cultivation (ha)	Maize production (tonne)	Maize production (tonne/ha)
1997	181.300	243.600	1.34
1998	269.100	269.100	1.00
1999	211.700	103.800	0.49
2000	211.700	169.400	0.80
2001	134.000	201.000	1.50
2002	341.800	346.900	1.01
2003	313.900	117.200	0.37
AVERAGE			**0.93**

Table 25: Maize production in Shinyanga. Source: (MAFC 2008)

As can be seen in Table 25, maize production is fluctuating significantly per season, depending on the annual rainfall. Therefore, a time series of annual maize production is needed to estimate the average yield. However, the national statistics of Table 25 include Kahama and Bukombe district, which are in West Shinyanga and receive significantly more annual rainfall compared to East Shinyanga. Table 26 shows maize production estimations in Shinyanga per district in 2006, based on field assessment:

District	Area (ha)	Yield (tonne)	Productivity (tonne/ha)
Shinyanga urban	2.342	2.342	1.00
Shinyanga rural	63.800	44.680	0.70
Kishapu	15.778	11.045	0.70
Maswa	48.921	34.244	0.70
Bariadi	65.000	97.500	1.50
Meatu	31.826	25.460	0.80
TOTAL east-Shinyanga	**227.667**	**215.271**	**0.95**
Kahama	116.993	116.993	1.00
Bukombe	69.200	138.400	2.00
TOTAL Shinyanga	**413.860**	**470.664**	**1.14**
Factor difference eastern districts and whole Shinyanga			**0.83**

Table 26: Estimated maize yield in Shinyanga districts in 2006, based on field assessment. Source: Shinyanga regional government, department of agriculture (Mashaka 2007).

As can be seen in Table 26, 45% of maize is produced in these two districts. As a result, average maize yields are a factor 0.83 lower for the eastern districts as for the whole of Shinyanga. Applying this factor on the average production of Table 25 results in an average maize production of 0.77 tonne/ha for East Shinyanga.

However, this number is highly uncertain since there is no time series of maize production per district in Shinyanga available. Therefore, I collected more literature, as shown in Table 27:

Average maize yield (tonne/ha)	Source	Remarks
0.80	(Mungroop *et al.* 2000)	Meatu district, Shinyanga
1.30	(Shinyanga District Council 2006)	Year 2004
1.00	(Shinyanga District Council 2006)	Year 2005
0.75	(Mdadila, 1998 in Limbu, 1999)	Average for Shinyanga region
0.80	(Van der Linde *et al.*, 1998 in Limbu, 1999)	Average for Lake Zone, poorest conditions
Maize test plots (tonne/ha)		
1.33	(HASHI 1998)	Year 1994
1.64	(HASHI 1998)	Year 1995
0.85	(HASHI 1998)	Year 1996
0.56	(HASHI 1997)	Year not known

Table 27: Average maize yield estimations and maize yields at maize research plots in Shinyanga region.

Again, maize yields show enormous variations. Considering the above data, I estimated an average maize production of 0.80 tonne/ha for East Shinyanga.

Estimation of average maize market price in east-Shinyanga

I estimated the average maize market price from different sources, as shown in Table 28. I assumed an average annual maize price of Tsh 4.500/debe, which is US$ 207,50/tonne.

Maize price (Tsh/debe)	Maize price (US$/tonne)	Source
6.000	276,67	Survey data, see appendix D.
5.000	230,56	
5.500	253,61	
4.500 – 5.000	207,50 – 230,56	Shinyanga regional government, department of agriculture, prices October 2007 (Mashaka 2007)
3.500 – 5.000	161,39 – 230,56	Shinyanga Rural District Government, annual price variation (Mapundo *et al.* 2007).

Table 28: The market price of maize in East Shinyanga by different sources.

Labour intensity of maize cultivation

The labour intensity of maize cultivation was determined by taking averages of the studies used to determine the shadow cost of labour (See Table 7):

Parameter	(Mdadila 1998 in Limbu 1999)	(Van der Linde *et al.* 1998 in Limbu 1999)	(Ramadhani *et al.* 2001)	Average
Land preparation by hand hoe	28	40	14.6	27.5
Maize sowing	1	6	4.3	3.8
Weeding	26	20	16	20.7
Maize harvesting	10	10	12.1	15.8
Threshing		9	6.3	

Table 29: Labour intensity of maize cultivation in Tanzania.

APPENDIX F: Rotational woodlot strata

Configuration of the seven strata of the rotational woodlot during two subsequent rotation periods, compared to the baseline situation:

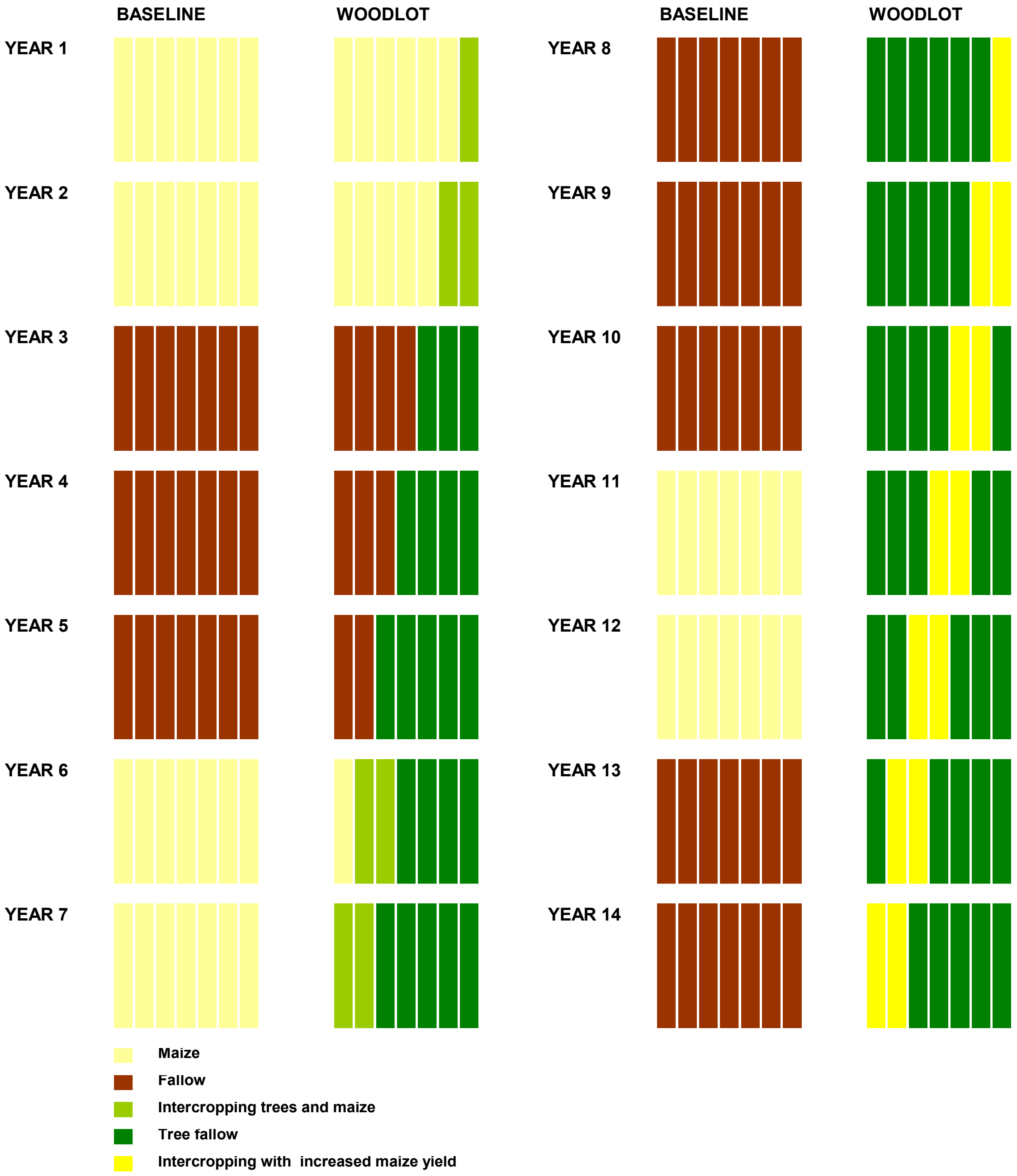

Figure 56: Configuration of the seven strata of the rotational woodlot over a time span of 14 years.