Comparing the Sustainability of Biomass Fuel Supply Options for a Small Scale Gasification Project in Rural Uganda

Master of Science Thesis in the Innovative and Sustainable Energy Engineering (ISEE) Nordic Master Degree Programme, 2010-2012

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Göteborg, Sweden, 2012
Report No. T2012-385

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Abstract

Recent studies have shown the potential and economic viability of biomass gasification based systems for electricity generation in rural Uganda (e.g. Buchholz et al., 2010; Furtado, 2012). The implementation of these systems hinges on the sustainability of fuel supply. A growing population using biomass for over 90% of their primary energy needs and land use change from forests being cut for small scale farming and large monoculture has caused Uganda to lose over 1/3 of its forest cover over the last two decades. Implementing a biomass based electricity system can further contribute to these problems if the biomass fuel supply is not sustainably managed.

Pamoja Cleantech AB is a startup company based in Stockholm which will soon implement a small scale (10 kW) biomass gasification pilot project in the Magala Village, Mityana district in rural Uganda. Pamoja recognizes the environmental issues involved in gasification projects in Uganda and wishes to move forward in implementing a sustainable biomass fuel supply.

This thesis addresses the question of which biomass fuel supply option is the best and most sustainable option for this project and future small scale gasification projects. In this paper, a sustainability framework has been developed in order to quantitatively compare the reliability, costs, and environmental and social impacts of different biomass fuel options for each individual site of operation in order to assure a fully sustainable supply.

First, the framework is presented along with details on its development from considerations of existing Criteria and Indicator (C&I) Frameworks and sustainable biomass standards. An explanation and justification is also given for the importance of each of the sustainability criteria. The best supply options available at a given site are then chosen and compared using the sustainability framework.

Results show that the three investigated supply options, buying firewood from the local market, purchasing agriculture residues, and implementing agroforestry and/or woodlot systems, are comparable economically in terms of the final price range for an oven dried ton of biomass supplied. Implementing outgrowing schemes, especially agroforestry systems, have significant advantages over the other two options in terms of potential social and environmental benefits. Although it is challenging to quantitatively measure reliability, we consider implementing agroforestry and woodlot systems to be a more reliable fuel supply option than purchasing firewood or agriculture residues.

The recommended biomass supply for this project is using agriculture residues in the short term and local fuelwood as a backup while also implementing outgrowing schemes and growing trees locally in woodlot or agroforestry systems. This will increase the reliability of the fuel supply in the long term, as well as maximize local social and environmental benefits.

Keywords: *biomass, bioenergy, gasification, sustainablity, framework, Criteria and Indicator (C&I) Framework, Uganda, East Africa*

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List of Acronyms and Abbreviations

APL – All Power Labs
C&I – Criteria and Indicator
CREEC – Center for Research in Energy and Energy Conservation, Uganda
FAO – Food and Agriculture Organization of the United Nations
GDP – Gross Domestic Product
GEK – Gasifier Experimenter's Kit
HFO – Heavy Fuel Oil
HPS – Husk Power Systems
IEA – International Energy Agency
KTH – Kungliga Tekniska Högskolan (Swedish Royal Institute of Technology)
MEMD - Ministry of Energy and Mineral Development, Uganda
MDG – United Nations Millennium Development Goals
NEMA – Ugandan National Environment Management Authority
NPV – Net Present Value
odt – Oven dry ton (metric ton with 0% moisture content)
OECD - Organisation for Economic Co-operation and Development
O&M – Operation and Maintenance
PV - Photovoltaic
REA –Rural Electrification Agency, Uganda
RET – Renewable Energy Technologies
SFM – Sustainable Forest Management
SIDA – Swedish International Development Cooperation Agency
SRC – Short Rotation Coppice
UBOS – Uganda Bureau of Statistics
UN – United Nations (2500 UGX = $1 USD, 2012 average)
UNFCCC—United Nations Framework Convention on Climate Change
USAID – United States Agency for International Development
USD – United States Dollars ($)

Units

Ha – Hectare (10,000 m^2)
kW – Kilowatt
kWh – Kilowatt hour
MJ - Megajoules
MW – Megawatt (10^6 watts)
UGX – Ugandan Shillings ($1 USD = 2500 UGX, May 2012)

1. Introduction

1.1. Problem Definition

Pamoja Cleantech AB, a Swedish startup company, is implementing a pilot small scale electricity generation system based on biomass gasification for use in rural Uganda. This system uses a 10kW gasifier which runs on solid biomass fuel. This gasifier can be used to power large electrical loads currently supplied by diesel generators (ex. telecom towers, agriculture processing equipment), as well as provide electricity access for rural communites, including local businesses households.

According to the UN, access to sustainable energy is necessary in achieving the Millenium Development Goals (MDGs) by contributing to local development by improving economic conditions and providing the necessary energy for education and health services among others (UN Energy, 2005). Uganda has one of the world's lowest electrification rates at 9% nationwide and 4% in rural areas (IEA, 2011). This gasification system has a great potential improve livelihoods and contribute to local development by providing electricity access to communities in rural Uganda.

In addition, the people of Uganda use biomass, mostly firewood and charcoal, for over 94% of primary energy consumption (MEMD, 2009). The population, 34.5 million as of 2011, is also growing rapidly at 3% per year (World Bank,2012). Due to the large and growing population, the large demand for biomass for energy, and the need for agricultural land, a huge pressure has been placed on natural forests, and Uganda has lost over 36% of natural forest cover since 1990 (FAO, 2010) . Therefore, great care must be taken when implementing an electricty generation system which relies on a biomass fuel supply. A sustainable supply must be implemented in order not to contribute to the growing issue of deforestation and forest degradation.

Biomass gasification based systems for electricity generation have proved to be a suitable and economically viable system for rural electrification in Uganda (e.g. Buchholz, *et al.*, 2010). The success and long tem sustainability of these systems ultimately depends in a large part on the reliability and sustainbility of the biomass fuel supply. The issue is then to assess and attempt to quantitatively compare the different biomass fuel supply options in terms of sustainabilty, determine the best option on a project basis, and implement the most sustainable option going forward.

This thesis will also go into questions of what is meant by sustainability and how to assess sustainability for biomass and for bioenergy projects. This will lead into the main question this thesis will address, which is *"Which biomass fuel supply is the best and most sustainable option for this pilot project and for future projects?".*

1.2. Aims & Objectives

Aims

The primary aim of this thesis is to analyze and quantitatively compare the different options available in supplying biomass fuel to the gasifier in Pamoja's pilot project. This will be done by developing a sustainability framework and then applying the framework to this project case in order to compare the biomass options in terms of the criteria of reliability, cost, social impacts, and environmental impacts. By presenting the quantiative comparison of the sustainabilty of available biomass fuel options, the aim is to determine which options are the most sustainable and to successfully implement these best supply options for the upcoming pilot project.

Another main aim of this thesis is to develop and present a suitable framework which can be applied to assess the sustainability of biomass supply options both for similar bioenergy projects in the future. By applying this framework to this pilot project case and assessing the results, a discussion will be made on the suitability of this framework as a tool for assessing the sustainability of biomass fuel supplies. It is my hope that this framework will prove useful as a tool and can be revised, improved upon and applied for future Pamoja projects and other bioenergy projects.

Objectives

- Present the sustainabilty framework, defining the sustainabilty criteria (reliability, cost, social impacts, environmental impacts) and their importance.
- Compare the available biomass supply options against the sustainabilty framework, giving a score for each option and criteria that is based on information from field work and/or literature review.
- Analyze the results to determine the best fuel supply options for this project, present detailed recommendations on the next steps needed to implement these supplies, and to determine the effectiveness of this framework as a tool in measuring sustainability of biomass supply options.

1.3. Methodology

The sustainable biomass framework which will be used in this thesis was developed while in Uganda and in collaboration between myself and Pamoja's internal advisor Thomas Buchholz, who holds a PhD in Sustainable Bioenergy Systems from the State University of New York. The framework that has been developed considers existing sustainable biomass frameworks and standards, Criteria and Indicator (C&I) frameworks on sustainable forest management, and Pamoja's own concerns on sustainability. The framework, its development, and a description of each sustainability criteria and their importance will be presented in Section 3.

After presenting the framework, the best or most feasible supply options for this pilot project will then be chosen and justififed based on information and observations from the field visits. The best supply options, in this case purchasing firewood, purchasing agriculture residues, and implementing outgrowing schemes, will then be compared using the sustainability framework presented in Section 3.

In Sections 4-6, these three best supply options for this project will be assessed against the framework. For each supply option and criteria, quantitative information will be gathered from field studies and interviews while in Uganda and from a relevant literature review. Data from field studies and site visits will be supported and confirmed by data from literature review and this information gathered will be used to assess how well a given option meets the sustainability criteria.

For each supply option, a score or ranking will be given for each criteria that is justified or supported by information gathered. In Section 7, the results and scores will be compiled and the supply options compared. A discussion of the results will follow along with a discussion on the suitability of the framework as a tool for assessing sustainability of the biomass options for this and future projects.

2. Background

2.1. Uganda

2.1.1. Geography and Environment

Uganda is a landlocked country in East Africa between latitudes 4°N and 2°S, and between longitudes 29° and 35°E with a total surface area of 241,550 km^2. Uganda is directly north of Lake Victoria (and Tanzania) and bordering Kenya to the East, the Democratic Republic of the Congo to the West, Rwanda to the South West and South Sudan to the North. Figure 1 below shows the localtion of Uganda on world and regional maps.

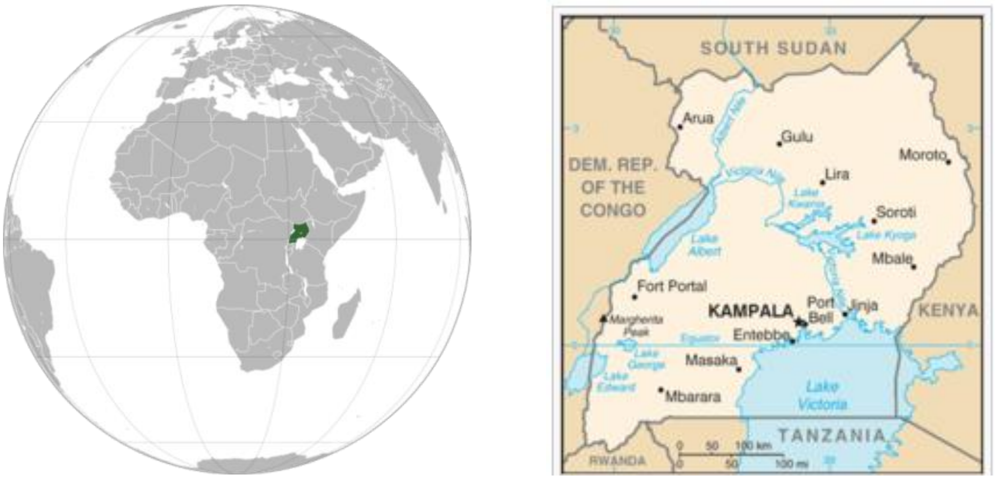


Figure 1: World and regional maps showing Uganda (taken from Wikipedia, 2012)

Over 36% of the total surface area is represented by small scale farmland as a large majority of the growing population relies on subsitance agriculture. In addition, since biomass(mainly fuelwood) represents the large majority of their primary energy consumption. Conversion of woodlands to agricultural land and growing biomass consumption has increased pressure on natural forests in the area. The FAO estimates that over 36% of forest cover has been lost since 1990 (FAO, 2010). Figure 2 below presents the land use distribution in Uganda as of 2005.

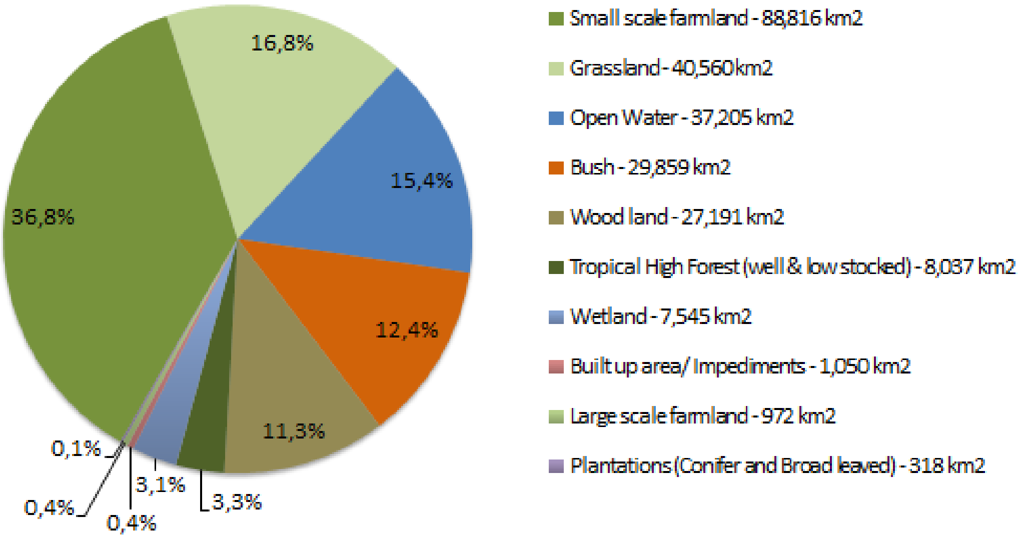


Figure 2: Surface Area Use Distribution in Uganda as of 2005 (modified from FAO, 2010)

This growing issue of deforestation has many negative impacts on the society and environment, including loss of biodiversity, soil erosion and land degradation, and loss of livelihood and natural products from forests. Deforestation is a critical concern for Uganda at a national level, and it is one of the main environmental concerns of Pamoja when implementing and ensuring a sustainable biomass supply.

Uganda is also very important in terms of biodiversity, both in numbers and variety of species. The rich biodiversity present in Uganda is a result of Uganda's location between and including several ecological zones. Some of the main threats to the conservation of biodiversity are habitat loss and fragmentation, and unsustainable harvesting of natural resources. The main concern for biodiversity conservation is to protect the remaining areas with natural vegetation, mainly tropical high forests, which contain the majority of the species and ecosystems of concern (USAID, 2006).

2.1.2. Society and Economy

As of 2011, the population of Uganda is estimated to be around 34.5 million (World Bank, 2012a), and growing at a rate of around 3.2% annually, ranking 9th highest in the world for population growth rate. Uganda also has a very high population density at over 167 people per km^2 (World Bank, 2012a). The majority of the population, around 84.5%, live in rural areas. Of those in rural areas, around 27% live below the poverty line with inadequate access to clean water, health services, and education (World Bank, 2012a). The urban population is also continuing to grow rapidly at just under 6% annually as many move from rural areas into the city seeking jobs and better conditions. (World Bank, 2012a)

The World Bank lists Uganda as a 'low income' or developing country. Uganda has a GDP per capita of $515 USD compared to the average of $37,029 USD as of 2011. Agriculture is a very important part of the Ugandan society and economy, contributing to 24.7% of GDP in 2009 (World Bank, 2012a). In addition, the large majority of the 84.5% of Ugandans living in rural areas depend on subsistence agriculture for their livelihood.

Although still developing, Uganda has maintained a relatively stable macroeconomic condition and their GDP has been growing at over 7% annually through the 2000s. Uganda's economic growth has enabled some towards reaching the UN's Millennium Development Goals (MDGs), including halving the national poverty rate (56% in 1992 reduced to 24.5% as of 2010) Significant but slow progress has also been made towards reaching the MDGs of reducing hunger, reducing infant and child mortality, and providing access to universal primary education, among others (World Bank, 2012b).

Although relatively stable economically, Uganda still faces challenges of uneven progress and increasing inequality in regards to income and access to social services including education, health care and water. Uganda also faces challenges in managing its rapidly growing population, and managing and conserving natural resources, and properly managing the recently discovered oil resource (World Bank, 2012b).

2.2. Energy in Uganda

2.2.1. Primary and Secondary Energy

Biomass, mainly firewood and wood derived charcoal, represents the main source of primary energy for almost all Ugandans. Biomass represents around 94% of primary energy and is used mainly for cooking, the production of charcoal, and in small industies. (MEMD, 2009).

According to the Rural Electrification Agency, the total biomass consumption in Uganda was 27.7 million tons in 2006. Of this, 22.2 million tons, or around 80%, were used on the household level and 5.5 million tons, or around 20%, were used in small industies (REA, 2007).

The majority of the remaining primary energy supply (4.8% of the total) comes from imported petroleum sources, which includes gasoline, diesel, heavy fuel oil, kerosense, aviation fuel, and LPG. The remaining 1.1% is represented by electricity, mostly from hydropower.

Other renewables such as solar PV and biogas digesters represent only a minor contribution and are not included here. The figure below shows the primary and secondary energy supplies as of 2008, and more detailed information on the national energy balance of Uganda is given in Appendix A.

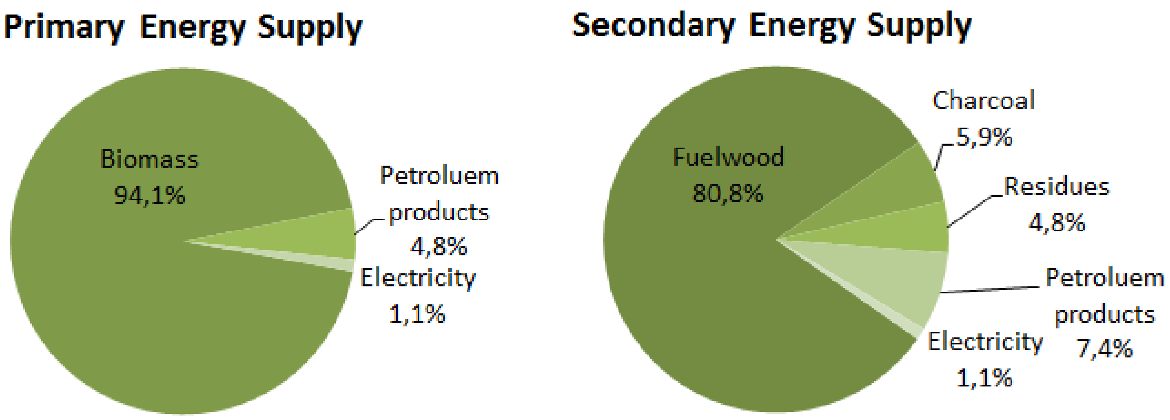


Figure 3: Primary and Secondary Energy Supply Mixes in Uganda (modified from MEMD, 2009)

The conversion from primary (naturally occuring or extracted) to secondary energy (useful energy carriers) represents a loss of around 38% resulting from losses in production and transmission, and the inefficient production of charcoal. In fact around 45% of the fuel wood is used for the production of charcoal. This current production is very inefficient, with an estimated 10kg of firewood needed to make 1kg of charcoal (MEMD 2009).

2.2.2. Petroleum Products

As of 2010, Uganda consumes over 935,000 m^3 of petroleum products annually, all of which are currently imported. Around 90% of Uganda's petroleum imports arrive through the port of Mombasa, Kenya, with 10% coming through the port of Dar es Salaam, Tanzania (MEMD, 2010). The long chain for petroleum products arriving through Uganda by truck means significant problems in terms of reliability and delays, and leaves Uganda very vulnerable to increases in fuel price .

In 2006, oil reserves were confirmed in Uganda in the Hoima district, near Lake Albert in Western Uganda. Recently in 2012, it has been confirmed that these deposits deposits hold at least 3.5 billion barrels of oil (BBC, 2012).

There are of course many issues raised over this newly discovered oil, including contracts and policy frameworks, corruption in Ugandan politics, and questions as to whether or not this discovery of oil will ultimately benefit the Ugandan people (The New York Times, 2011).

There are also issues of the people displaced by the oil refinery and other infrastructure, and of the possible risk to the biodiversity hotspot in the Albertine region (MEMD, 2010). Although progress has been slow, companies such as Tullow Oil, Total and CNOOC are currently working to operate in Uganda, and domestic production could soon make Uganda a net exporter of oil.

2.2.3. Power Generation and the National Electric Grid

Currently Uganda faces a major issue in energy defecit and low rates of electrictiy access. Uganda has a nationwide electrification rate of 9% and a rural electrification rate of 4%, among the lowest in the world (IEA, 2011).

As of 2007, the Rural Electrification Agency (REA) estimated a national electricity deficit, or difference between electrictiy demand and electricity production, of around 165 MW (REA, 2007). In addition, the REA reported an annual growth in electricity demand at around 7-9% (REA, 2007). This deficit results in an unreliable supply and daily power outages and load shedding which is an economic detrement to industry and businesses that need a reliable supply.

The majority of the electricity generated in Uganda (over 350 MW) currently comes from large hydropower plants near the town of Jinja where Lake Victoria meets the head of the White Nile river. Electricity production is also very sensitive to the water levels in Lake Victoria and capacity can decrease due to low levels.

Other larger electricity generation projects include thermal electricity generation (170 MW) mainly from Diesel and Heavy Fuel Oil (HFO), and biomass cogeneration plants using sugar cane bagasse (17MW). A table of the larger electicity generation projects operating as of 2010 is shown in Table 1 below.

Table 1: Installed Electricity Capacity in Uganda as of 2010 (UBOS, 2011b) by energy source.

Hydro Power Plants		**Thermal Power Plants**		**Bagasse (Thermal)**	
Plant Name	**Installed Capacity (MW)**	**Plant Name**	**Installed Capacity (MW)**	**Plant Name**	**Installed Capacity (MW)**
Kiira	120	*Electromax*	20	*Kakira*	12
Nalubale	180	*Kiira*	50	*Kinyara*	5
Kasese Cobalt	10	*IDA Plant*	50		
Kilembe Mines	5	*Aggreko II*	50		
Bugoye Tronder Power	13				
Mpanga	18				
Ishaha Ecopower	6.5				
Subtotal (MW)	**352.5**	**170**		**17**	
Total Installed Capactiy (MW)	**539.5 MW**				

The Uganda Electricity Transmission Company was formed in 2001 under guidanceand authority from the Ministry of Energy and Mineral Development (MEMD) and currently manages bulk power purchases, manages national electricity imports and exports, and operates the national high voltage transmission grid (UETCL, 2012). UMEME also is in charge of owning and operating electricty distribution and trasnsmisson equipment under 33kV, and purcahses electricity from UETCL (Umeme, 2012).

The Uganda Electricity Generation Company (UEGCL) currently operates the main hydropower stations (Nalubaale and Kiira), and other hydropower generation projects are currently underway to increase generation capacity (UEGCL,2012).

However, Uganda has also had difficulty in attracting foreign investment in large energy projects possibly due to corruption and political issues. There are also the significant problem of electricity losses due to poor grid infrastructure. Transmission losses are high due to outdated grid infrastructure, and were estimated at around 38% in 2008 (MEMD, 2009).

In 2006, the estimated value lost due to electrical outages in Uganda was 10.2% of sales (World Bank, 2012). As a result, many businesses and private homes also operate backup diesel generators to assure a constant and reliable supply of electricity. This backup generation capacity is estimated at around 80 MW (Unique, 2006).

2.2.4. Electric Power Generation and Renewable Energy Technologies

Ugandas faces serious challenges and considerations in moving forward with increasing centralized generation capacity and improving the state of the national electricity grid. However over 84% of Ugandans live in rural areas and in most cases it is not cost effective for the UETCL and UMEME to connect these houses to the grid.

This is due to the long distances between these rural settlements as well as high costs to connect a household and to meter the electricity use. Costs to extend the grid amd to connect these households are estimated at around $1000 per household (SharedSolar, 2011). In addition, most rural customers only consume a relatively small amount of electricity and therefore due to the distance and costs, it is not worth it for the utilities to connect households.

The MEMD and REA in Uganda have recognized that distributed generation from renewable energy sources is the best potential solution for providing electricity to rural communities. The REA has estiamted the generation potential from renewable energy sources, and the estimates are shown in Figure 4 below.

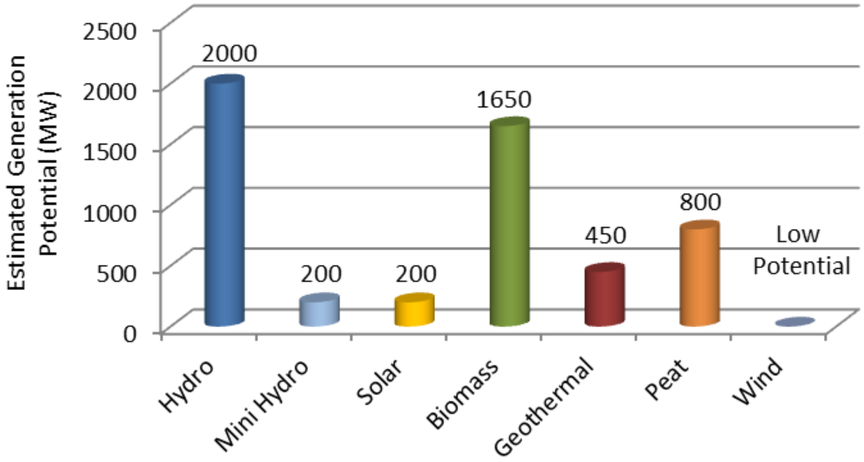


Figure 4 : Estimated Electrical Generation Capacity from Renewable Energy Sources, (REA, 2007)

Peat is listed in this generation potential, althought is not considered by the UN to be renewable. Rather it is considered to be a fossil fuel, due to extraction rates largely exceeding the slow growth rates (It should also be noted here that there are no significat coal reserves in Uganda).

The REA has outlined a plan for imroved access to electricity and energy services including home biogas systems, household solar systems, and imroved cooking stoves, among others. However there are a number of challenges to the development and implementation of distributed RET systems, including the high initial costs and lack of financing, and inadequate acesss of information on the technologies availalble and technical implementation (REA, 2007).

Progress has been slow, but is continuing and there is currently a large growth of small scale solar household systems, which include a small solar panel for powering a LED light and charging cell phones, and as of 2007 their capacity is estimated at 200 kWp (REA, 2007).

These small solar systems are in the low watt range and are very useful for lighting and charging phones, however they are not suitable for large loads in rural areas that are currently being run on diesel engines. Pamoja hopes to contribute to this renewable distributed generation by implementing their pilot biomass gasification system which provides power around the 10 kWp range which is more suitable for larger loads and for whole power to a community.

2.2.5. Energy Use in Rural Households

Nationally, around 310,000 households are connected to the grid as of 2008. Current estimates of rural electrification are around 4%, or less than half the goal set by the MEMD and REA. Without access to electricity, those in rural communities have to spend money on more expensive, inefficient and potentially harmful energy sources such as kerosene for lighting, and dry cell batteries. Table 2 : Source of Lighting as a Percentage of Rural Households (UBOS, 2010)Table 2 below shows the energy sources used for lighting in rural households, with the majority of households using kerosene lighting from 'tadoobas' and lanterns.

Table 2 : Source of Lighting as a Percentage of Rural Households (UBOS, 2010)

'Tadooba'	Lantern	Electricity	Other	Total
76.3 %	12.2 %	3.8 %	7.7 %	100%

Research from the UN Millenium Villages shows that the poor members of rural communities are spending up to $5 USD per month on kerosene, dry cell batteries, and other sources. This consumption is equivalent to around 1.5 kWh of electricity, giving a price of $3 USD /kWh. Even with this very high price, the rural poor are still willing to pay to have access to basic, inefficient and harmful energy sources. The implementation of small home solar systems has been helpful, although slow due to high initial costs and an electricity cost of around $2/kWh for the product lifetime (SharedSolar, 2011) .

The majority of the energy consumption, however, is the use of biomass, especially firewood, used for the cooking of food. Per capita consumption in rural areas is estimated at 680 kg of firewood per year (REA, 2007). In addition, the majority of households use inefficient three-stone open fires and open charcoal stoves for cooking households, while only an estimated 8.5% percent of households use improved stoves (UBOS,2010).

Figure 5: The 'Tadooba' kerosense candle vs. the Firefly Home Solar System from Barefoot Power (picture from WorldChanging, 2010)

2.3. Pamoja's Pilot Project Description

2.3.1. The Pamoja Company and Project

Pamoja Cleantech AB is an international startup company based in Stockholm which is currently in the process of planning and implementing a small scale biomass gasification project for electricity generation in rural Uganda. Pamoja is a social business and is working with an innovative and inclusive business model to benefit the local community, providing electricity services, employment and revenue.

The Green Plant concept intends to provide electricity to the many telecom towers throughout Uganda that currently run on diesel generators while also providing electricity access to nearby rural communities. This system will enable the telecom industry in the area to transition from a complex and expensive diesel fuel chain to a cheaper and more environmentally friendly renewable solution. This will also provide electricity access to rural communities who previously had no access, enabling local social and economic development.

Pamoja has estimated that there are over 2,500 such telecom towers in Uganda alone that currently run on diesel generators. Based on the UNFCCC methodology for calculating emission reductions, Pamoja calculates that one green plant will save around 76 tons of CO_2 equivalent annually, with values increasing to around 120 tons of CO_2 equivalent annually over the project lifetime (Pamoja, 2012a).

The system will source the biomass fuel from appropriate agriculture residues and from trees grown in agroforestry or woodlot systems. In addition to the potential local employment provided from operating the gasifier, sourcing the biomass from local farmers can also provide additional sources of income. A conceptual drawing of the power plant and local interactions are shown in Figure 6 below.

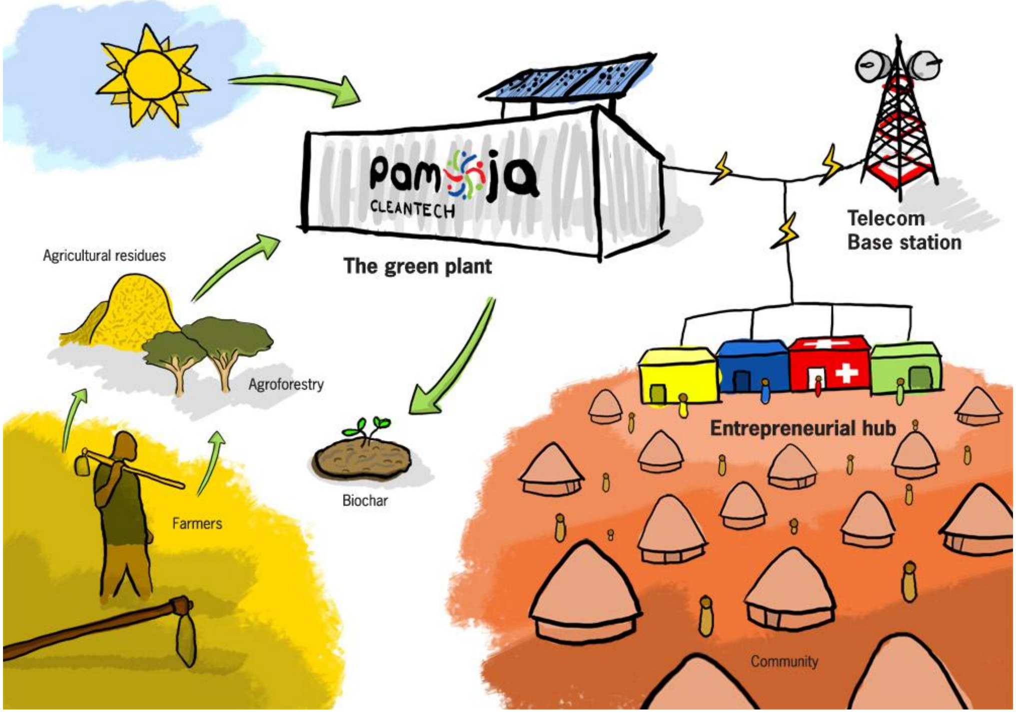


Figure 6: Conceptual Drawing of the Pamoja Green Plant and Community (Pamoja, 2012b)

2.3.2. The Feasibility Study, Green Plany Pilot Project and Local Partners

Pamoja is currently working with academic, industry and NGO partners in Uganda to implement this pilot project as a proof of concept. This pilot project is part of the Millenium Science Initiative (MSI) and financed by the World Bank through Pamoja's academic partner, the Center for Research on Energy and Energy Conservation (CREEC) at Makerere University, Kampala.

Pamoja conducted a feasibility study this spring through the SIDA Innovations Against Poverty (IAP) project in order to investiage the potential of this system and economic feasibility. The study was successful and showed a great potential in replacing diesel generators in large loads electrical loads such as telecom towers, water pumps, and agriculture processing machines and also in providing electricity to communities. The study also showed customers and community members willingness to pay since they currently pay for expensive low quality energy that can be replaced by this system.

In this pilot project, Pamoja will deliver and install a system including 10 kW gasifier, 1 kW solar panels, an inverter, batteries, and other small infrastructure which will be installed at the Magala Village in the Sekanyonyi sub-county in the Mityana district.

With the help of a grant from SIDAs IAP program, Pamoja will also begin to plant trees for a woody biomass fuel supply by implementing a tree nursery with the help of NGO partner, Vi-Agroforestry. Pamoja is also working with UIRI (the Ugandan Industrial Research Institute) for technical and maintainance support and also to enchance technology transfer to Uganda.

2.3.3. Funding and Business Model

Pamoja's current business model depends on an 'anchor load', meaning a relatively large and reliable electricity load, usually a business which is currently operating a diesel generator. Pamoja's original concept involved having a telecom tower as an anchor load. However, there are many other large stable electrical loads currently running on diesel generators in rural Uganda which can serve as anchor loads, for instance agriculture processing machines and water pumps, among others.

In an agreement with this customer, a more stable source of income is ensured since generated electricity is sold in large amounts to a business or customer able and willing to pay for cheaper cleaner electricity. This is a crucial part to the proposed business model, as it can make the entire system economically sustainable. In fact, a study modelling this system in HOMER shows that the size of the electricity load has great impact on the final cost per kWh to generate this electricity (Furtado, 2012). Therefore it is economically benefical to operating the gasifier as close as possible to the rated capactiy, supplying an anchor load and the local community.

Another consideration Pamoja needs to address is the system for metering and payment for the electricity provided to the community. Pamoja is currently considering options such as prepaid metering systems, prepaid systems using mobile phone money, or setting a monthly fixed rate and using fuses to limit consumption to certain levels.

2.3.4. The Local Community – Magala Village

Pamoja's pilot project will be installed in the Magala Village in the Sekanyonyi Sub-County, Mityana District. The Magala village itself covers an area of around 2 km^2 (200 ha) and includes 70 households, with an average of around 8 members per household. The village is located about 2-3 hours by car from the capital city Kampala, and has GPS coordinates .52803 N, 32.13436 E. The figure below shows a google map image of the community area overlayed with points of interest such as households, the cooperative's maize milling machine, and nearby telecom antenna.

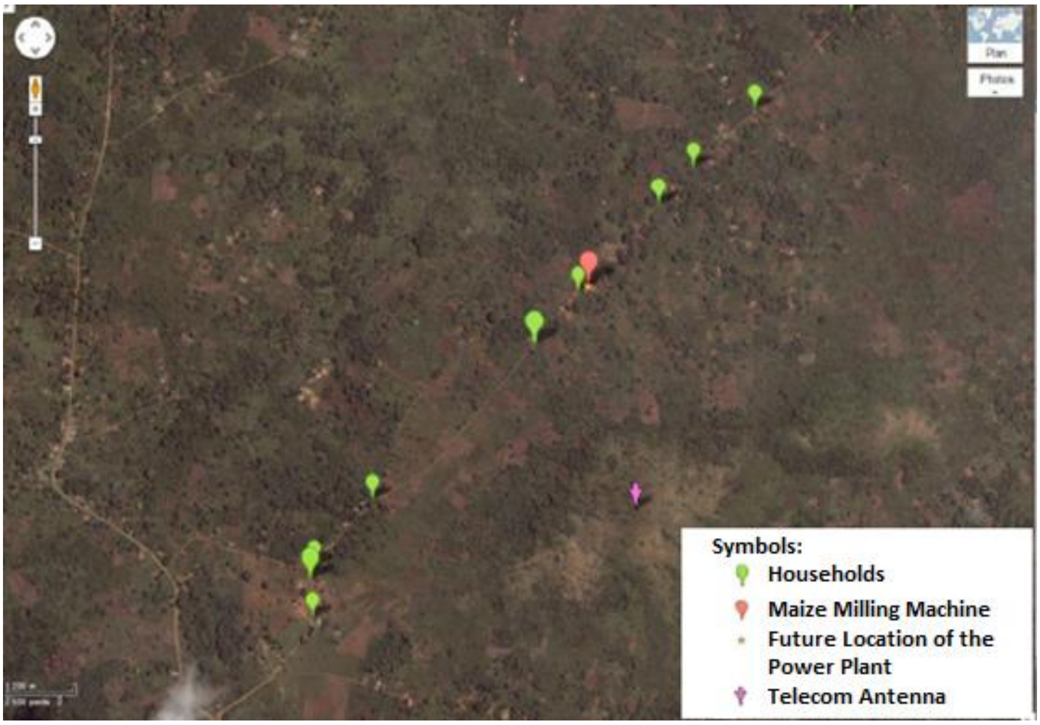


Figure 7: Map of the Magala Village Showing Key Locations (Pamoja, 2012a)

Pamoja's pilot project will be installed near the central point of the Magala village. Pamoja will work closely with the Magala Growers Cooperative, a Farmer Cooperative registered with 250 members which currently owns and operates diesel engine driven maize husking and milling machines. Pamoja's plant plans to supply power to drive the maize processing machines, replacing the diesel engine. Pamoja also plans to install a mini-grid providing electricity access to the many households in the area.

During our stay in Uganda, we conducted general and baseline surveys in the Sekanyonyi community. In the general interview, we sat down with the chairman and other members of the board of the farmer cooperative in a meeting room in the village. In this meeting we met the leaders of the cooperative, got information on the size of the community and saw firsthand their motivation and organizational capacity in terms of their savings and loan capacity, and ability to successfully run a maize processing business. The maize mill they have in the community was paid with some support from Vi-Agroforestry, however now it is successfully operated by the farmer cooperative. The Magala Growers cooperative has harvest records and projected harvest records showing they expect 1 ton of Maize and 500 kg of coffee per cooperative member per season.

In working with this community and farmer cooperative for this pilot project, Pamoja hopes to develop the community economically, providing electricity to the community and enabling local businesses. Pamoja also intends to source local workers and train them to operate and maintain the gasifier. In addition, the farmer cooperative can also be helpful in growing and harvesting the biomass, as well as storing and processing it for use in the gasifier.

2.4. Gasification – The Process and Gasifier Technology

2.4.1. Overview, Background and History

The main source for power generation in this project is a 10 kW biomass gasifier developed by All Power Labs, California, USA. Biomass gasification is a thermal energy conversion process in which biomass is reacted at high temperatures with a limited supply of oxygen. In the presence of high temperatures, around 800-1000 °C and in the absence of oxygen, the solid biomass fuel is converted into a combustible gas which is then used in an internal combustion engine and generator head for electricty generation.

The process of gasification is a proven process that has been used for energy purposes for over 180 years. First uses were producing a flammable gas for heating and cooking. Later, wood gasifiers were used extensively to run motor vehicles in Europe during shortages of petroleum in WWII. Currently gasification processes are used on a large scale to generate heat, electricity (or both in CHP plants), transport fuels, and synthesis of liquid fuels and other chemicals (McKendry, 2001).

Biomass gasification has recently been studied as a solution to small scale off grid electrification, and studies have shown that this technology is a technically feasible and economically viable solution (Furtado, 2012; Buchholz, 2010). Gasifiers have already been used extensively through India, through the Husk Power Systems (HPS) company (HPS, 2012). This pilot project represents another significant step in the adaptation of this proven technology for use in small scale rural electrification in East Africa.

2.4.2. The gasification process

Biomass gasification is a thermochemical conversion process which converts solid biomass fuel into a combustible gas in a partial combustion process in a limited oxygen environment. The process of gasification can be divided into 4 processes occurring at different zones within the gasifier. First, drying occurs as water is evaporated from the biomass in the presence of heat.

Second, pyrolysis (or devolatilization) occurs around 200-300 °C. In the pyrolysis zone, the solid biomass is reacted with heat in the absence of oxygen, releasing volatile gases and tar and leaving charcoal.

Thirdly, oxygen, or in this case air, is introduced, combusting or oxidizing the gas and charcoal. This combustion reaction produces heat and drives the pryolysis reactions as well as the reduction reactions in the final step of reduction. The three chemical reactions occuring in the oxidation zone are outlined below (Buragohain, et al., 2010).

Complete oxidation of Carbon $C + O_2 \rightarrow CO_2 + 406\ \mathrm{kJ/gmol}$

Partial oxidation of Carbon $C + {}^{1}/_{2}\, O_2 \rightleftarrows CO + 268\ \mathrm{kJ/gmol}$

Oxidation of Hydrogen $H_2 + {}^{1}/_{2}\, O_2 \rightarrow H_2O + 242\ \mathrm{kJ/gmol}$

In the reduction zone, the hot carbon in the charcoal reacts with steam and carbon dioxide at around 800-1000 °C, producing a combustible gas consisting mainly of carbon monoxide (CO) and hydrogen gas (H_2). The four main chemical reactions, among others, occuring in the oxidation zone are outlined below (Buragohain, et al., 2010).

Water- gas reaction $C + H_2O \rightleftarrows CO + H_2 - 131.4\ \mathrm{kJ/gmol}$

Bounded Reaction $C + CO_2 \rightleftarrows 2CO - 172.6\ \mathrm{kJ/gmol}$

Shift Reaction $CO_2 + H_2 \rightleftarrows CO + H_2O - 42\ \mathrm{kJ/gmol}$

Methane reaction $C + 2H_2 \rightleftarrows CH_4 + 75\ \mathrm{kJ/gmol}$

Figure 8 below presents a visual representation of the All Power Labs downdraft gasifier as well as an overview of the 4 processes involved in gasification. In additon, a more detailed table of all the chemical reactions involved in the entire process of gasification, the zones in which they occur, and temperature ranges can be found in Appendix B.

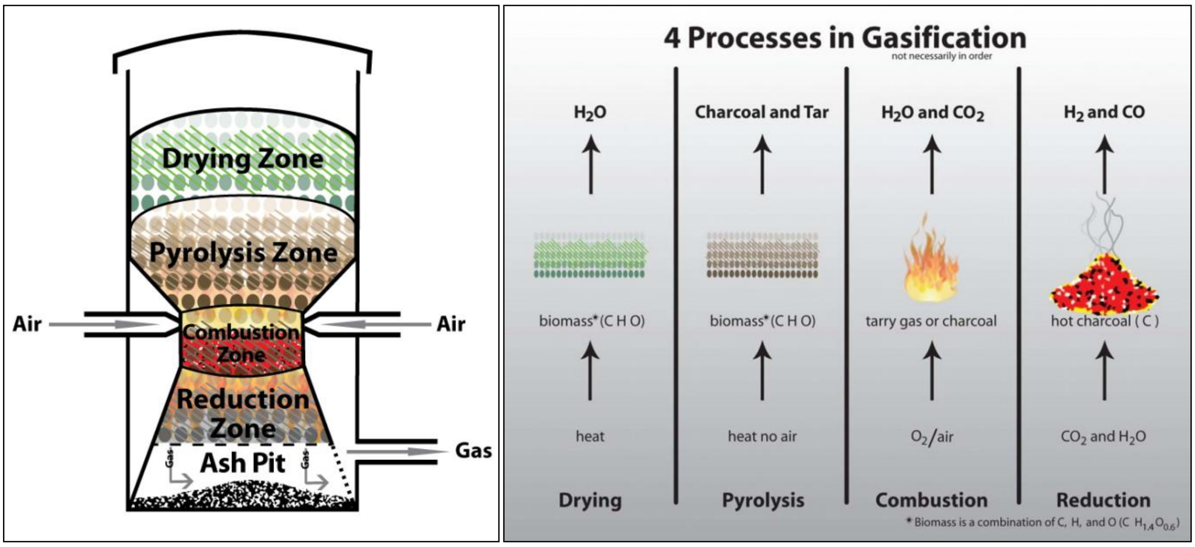


Figure 8: The downdraft gasifier with its 4 phases of conversion (APL, 2012 a,b).

The combustible gas resulting from these reactions is called producer gas (or syngas if produced using pure oxygen). Producer gas generally has a relatively low CV of around 4-6 MJ/Nm3, and generally contains three combustible gasses (CO, H2, CH4) and three non-combustible gasses (N2, CO2, and H2O) (McKendry, 2001). After the gasification process, the producer gas is cleaned by dry filters to remove tar, cooled, then used directly in an internal combustion engine and generator set, producing electricity.

The gasifier used in this project is the GEK Power Pallet developed by All Power Labs, which is a fixed bed downdraft design, described later in the next section. Typical gas composition of producer gas from a downdraft gasifier running on wood is given in Table 3 below.

Table 3: Typical Gas Composition for a Downdraft Gasifier Running Woodfuel (Strassen, 1995)

Gasifier type: Fuel:	Downdraft: Wood
Moisture Content (fuel in - % wet basis)	10-20
Hydrogen (%)	12-20
Carbon monoxide (%)	15-22
Methane (%)	1-3
Carbon dioxide (%)	8-15
Nitrogen (%)	45-55
Oxygen (%)	1-3
Moisture Content (Nm3 H2O/Nm3 dry gas)	0-0.06
Tar (g/Nm3 dry gas)	0.1-3
Lower Heating Value (MJ/Nm3 dry gas)	4.5-5.5

2.4.3. The Gasifier – The APL GEK Power Pallet

The gasifier that Pamoja will use for this particular pilot project is the 10 kW GEK Power Pallet developed by All Power Labs (APL) based in Berkley, California. APL has years of experience working and improving their Gasifier Experimenter's Kit (GEK) System and is a global leader in small scale gasification technology. APL advertises the GEK power pallet as an easy to use, compact and affordable gasifier which has been developed as a result of years of engineering improvements. The power pallet is an automated system with advanced electronic control resulting in improved combustion efficiencies and emissions, as well as waste heat recycling systems, allowing for greater flexibility in the choice of fuel, the quality of the fuel, and the moisture content of the fuel (APL, 2012c).

The Fixed – Bed Downdraft Gasifier Design

The gasifier developed by All Power Labs used in this project is a fixed-bed downdraft gasifier. Fixed bed designs are much simpler than fluidized bed gasifiers which are complex, more expensive and therefore only suitable for larger scale projects. This design is also preferred in this case over other fixed bed designs such as updraft and cross-draft gasifiers.

In this design, the biomass is gravity fed by a hopper, air is injected through nozzles into the combustion zone, and the combustible gas exits at the bottom of the gasifier. In this way, the tars produced in the pyrolysis zone must first pass through the combustion and reduction zones, resulting in a better cracking of the tars, and less tar in the producer gas, cleaner gas, and better combustion in the engine. In this design however, thermal efficiency can be lower since the gas exits at a high temperature (McKendry, 2001). In the GEK gasifier design however, this heat is utilized and used to help dry the incoming biomass fuel (APL, 2012c). A schematic and a picture of the GEK Power Pallet are shown in Figure 9 below and Figure 10 on the next page.

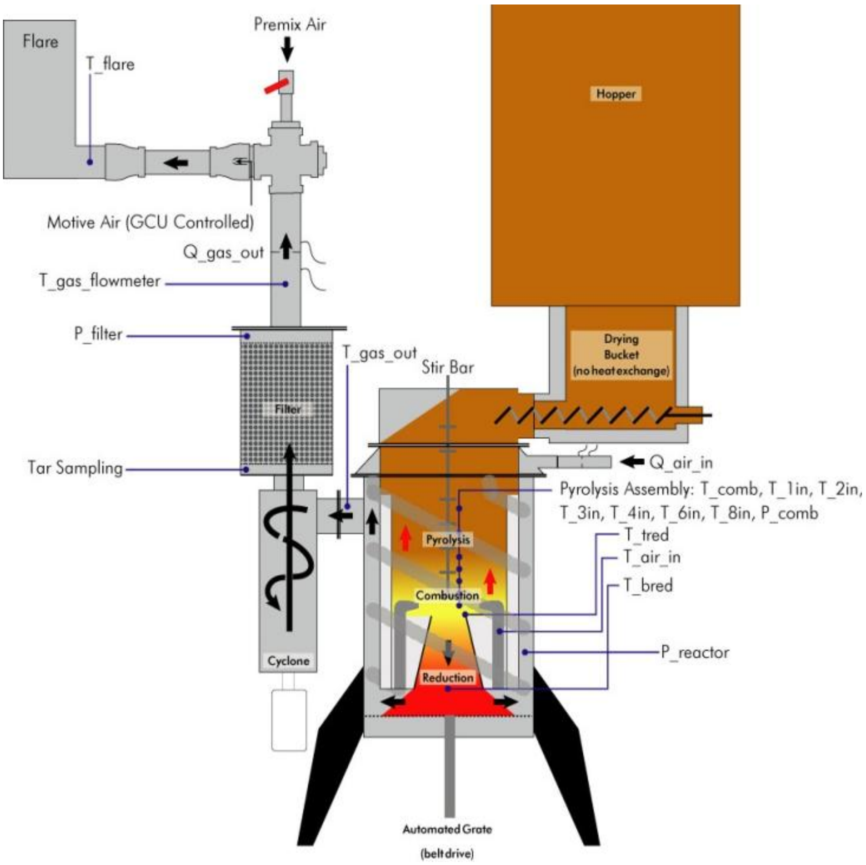


Figure 9: Schematic of the GEK Power Pallet (APL, 2012d)

This design is a simple and proven technology and is very suitable to producing a cleaner combustible gas on a small scale to be used in an internal combustion engine and generator set to produce electricity.

Figure 10: Picture of the GEK Power Pallet (APL, 2012c)

Table 4 below (left) gives ranges of of electrical output, gas flow output, and feedstock consumption for the 10kW GEK Power Pallet. In addition, Figure 11 below (right) below gives some general information on the relations between the amount of producer gas and electricity resulting from the gasification of 1 kg of biomass.

Table 4 (Left): Ranges of Electrical Output, GasFlow Output, and Feedstock Consumption for the 10kW GEK Power Pallet (APL, 2012e)

Electrical Output	**2-10kW**
Gas Flow Output	5-27 m^3/hr
Feedstock Consumption Range (dry weight)	2.5–14 kg/hr

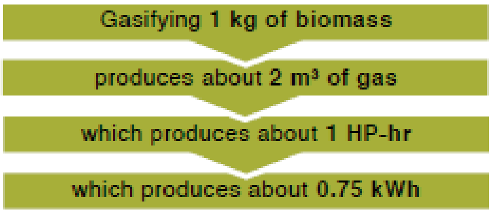


Figure 11 (Right): General relations for the gas, shaft power, and electricity resulting from the gasification of 1kg of biomass (APL, 2012f).

2.4.4. Appropriate fuel for this Gasifier – Woody Biomass and Agriculture Residues

According to the APL website, for downdraft gasifiers there are certain specific requirements for the biomass feedstock fuel in order for the gasifier to work properly. In general, the biomass feedstock is one of the most important considerations in gasification projects as the operation of the gasifier and the quality of the gas produced can be very sensitive to these characteristics which depend on the design of the gasifier used. For the GEK gasifier systems, APL gives suggested ranges of the most important parameters for the biomass feedstock.

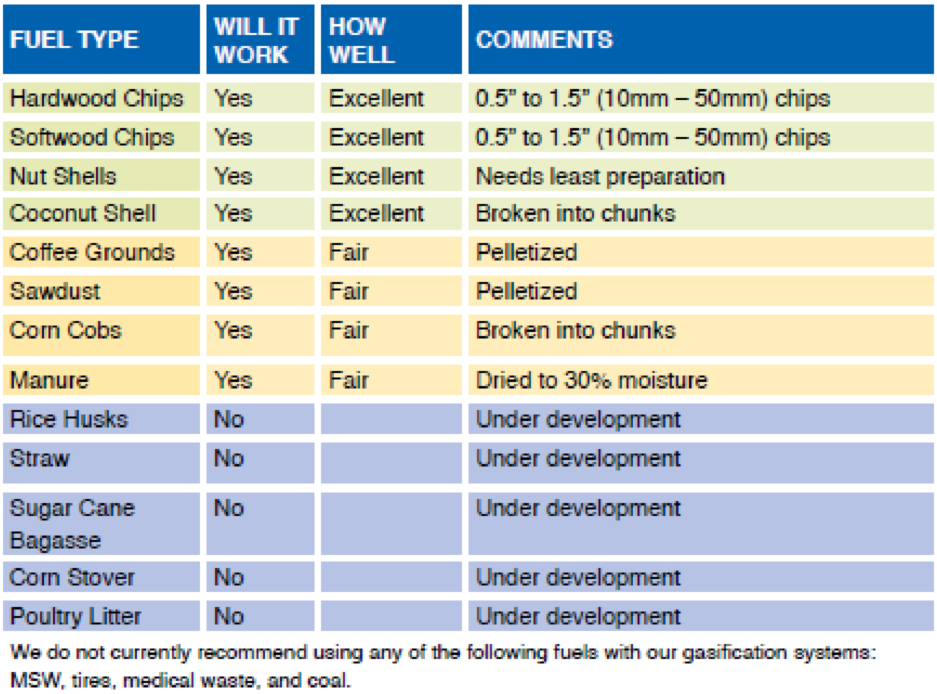
Table 5 : Suggested Ranges of Parameters for Biomass Feedstock for the GEK Power Pallet (APL,2012g)

Particle size	.5 - 1.5 inches (~10-50 mm)
Moisture content (% by dry weight)	less than 25%
Fixed carbon to volatile ratio	greater than 25%
Ash content (%)	less than 5%

Although the GEK Power Pallet system allows for a more flexible range of biomass feedstocks, it is still recommended to stay within these recommended ranges. Particle sizes to large or small can cause bridging and block the flow of air or biomass fuel. Moisture content higher than around 25% produces a gas with a very low heating value and can produce a gas with high tar content.

APL also presents a list of suitable biomass feedstocks that have been tested to work well in the gasifier. Table 6 below presents the list of those feedstocks that work excellently, fairly, and do not work.

Table 6: Suitable Biomass Feedstocks for the GEK Power Pallet (APL, 2012f)



FUEL TYPE	WILL IT WORK	HOW WELL	COMMENTS
Hardwood Chips	Yes	Excellent	0.5" to 1.5" (10mm – 50mm) chips
Softwood Chips	Yes	Excellent	0.5" to 1.5" (10mm – 50mm) chips
Nut Shells	Yes	Excellent	Needs least preparation
Coconut Shell	Yes	Excellent	Broken into chunks
Coffee Grounds	Yes	Fair	Pelletized
Sawdust	Yes	Fair	Pelletized
Corn Cobs	Yes	Fair	Broken into chunks
Manure	Yes	Fair	Dried to 30% moisture
Rice Husks	No		Under development
Straw	No		Under development
Sugar Cane Bagasse	No		Under development
Corn Stover	No		Under development
Poultry Litter	No		Under development

We do not currently recommend using any of the following fuels with our gasification systems: MSW, tires, medical waste, and coal.

As is shown in the table above, wood chips, and nut and coconut shells are the fuels which work best in the GEK gasifier. In fact woody biomass is the most common fuel for gasifiers and is generally preferred since woody biomass fits the criteria for a good feedstock, such as low moisture content, high energy density, and uniform composition.

However, there are other fuels such as manure and certain agriculture residues which are currently under development, and can possibly work in the GEK gasifier with some modifications. There are also many studies (Bingh, 2004; Okure 2006) that have investigated the potential of certain agriculture residues for energy production and fixed bed gasification in Uganda. The agriculture residues in Uganda with the most potential for biomass gasification are rice husks, groundnut (peanut) shells, coffee husks, sugar cane bagasse, and maize cobs. Table 7 in the nexty page lists some characteristics and generation potential of these residues.

A study at Makerere University in Kampala, Uganda investigated the performance of these residues in a fixed bed downdraft gasifier (Okure, et al., 2006). This study showed that the residue most suitable for gasification was groundnut shells, as they have low moisture content, high energy density, low ash content and the appropriate particle size, which allows the shells and air to flow well in the gasifier while requiring no processing.

Maize cobs also were found to work well, but had too large of a particle size. This can be solved by some minimum processing shredding them or breaking them into chunks, as has been done in Husk Power Systems gasificaiton pilot project in Uganda. Coffee husks were also an appropriate feedstock, but had a higher moisture content which produced a gas with a lower heating value. Rice husks had problems of small particle sizes and high ash content which caused bridging and ash slag formation which blocked flow in the gasifier.

Table 7: Energy Potential of the Agriculture Residues in Uganda Most Suited for Gasification (Bingh, 2004)

Fuel	*Rice Husks*	*Groundnut shells*	*Coffee husks*	*Sugar cane bagasse*	*Maize cobs*
Residue to Product Ratio (RPR)	.27	.48	2.1	.29	.27
Moisture Content (%)	12	8.2	15	49	7-8
Total Production (kt/year)	109	130	210	1800	1200
Residue Production (kt/year)	29.4	62.4	160	452.2	324
Calorific Value (kWh/kg)	4.44	5.98	4.61	5.25	3.89
Energy (GWh)	131	373	738	2374	910
Theoretical Potential (GWh)	39.3	111.9	221.4	712.2	273

The study also states that the variables such as moisture content and particle size which critically affect performance depend on local residue processing methods and drying methods. Table 8 below gives some of the fuel characteristics for these residues.

Table 8: Fuel Characteristics for Selected Agriculture Residues Used in a Downdraft Gasifier (Okure, et al., 2006).

Fuel	Rice Husks	Groundnut shells	Coffee husks	Sugar cane bagasse	Maize cobs
LHV (MJ/kg dry)	11.92	17.89	16.08	16.53	16.28
LHV (MJ/kg measured)	13.37	17.27	17.08	17.84	17.54
Moisture Content (%)	10-10.8	10-13.8	12.5-15	12.2-14	11.5-13
Bulk density (kg/m3)	120-135	95-105	220-320	155-170	170-185
Ash content (%)	21-22.5	3-6	6-7.5	2-4.5	2.2-2.5
Gas HV (MJ/Nm3 measured)	1.3-3.2	1.6-2.6	1.6-3.6	2.5-3.3	3-4.4
Angle of repose (°)	32.6	30.4	25.8	30	27
Hopper angle (°)	57.4	59.6	64.2	60	63

The suitable biomass sources such as wood from various sources and agriculture residues as appropriate for this gasifier project will be the feedstocks later compared in terms of sustainability criteria.

2.4.5. Amount of Biomass Fuel Needed per Year

Initial estimations of yearly biomass consumption for the 10kW gasifier was in the range of 50 oven-dried tons (0% moisture) of biomass per year. This first estimation assumes the gasifier runs for 11 hours per day at full-load with an efficiency of 1.4 kg fuel/kWh. (Unique, 2006).

The baseline study conducted by Pamoja in the Magala community (Pamoja, 2012a) gives a clearer estimation of the yearly biomass consumption for this gasifier. The baseline study first estimates the yearly energy demand for local households based on typical current energy consumption, then extrpolates this demand for the whole community. The study also estimates the electricty demand for the maize milling business based on current diesel consumption and the quantity of maize milled.

The baseline report then estimates the maximum yearly quantity of biomass needed. By taking the maximum daily value for the electricity demand, 72.6 kWh per day, extrapolating this value for the whole year, and using a more conservative assumption that the gasifier uses 1.5 kg of oven dreid biomass per kWh produced, maximum biomass consumption for the whole year is calculated. This value of 39.75 odt of biomass per year, as given in Table 9 below, represents a very high estimation of the consumption, based on a high electricity demand and very conservative biomass consumption estimates.

Table 9: Baseline Estimate of Daily and Yearly Electricity Load and Biomass Consumption (Pamoja, 2012a)

Load (kWh/day)	72.6
Load (kWh/year)	26,499
Max Biomass Consumption (oven dry kg/day)	108.9
Max Biomass Consumption (oven dry tons/year)	**39.75**

Based on this methodology for estimating yearly biomass consumption, it is safe to assume the biomass required to operate this gasifier will be a maximum of 40 oven dried tons (0% moisture) of biomass per year.

Quantity of Biomass Fuel Needed by the Gasifier Compared to Current Rural Consumption

As mentioned earlier in section 2.2.5, the average per capita consumption of firewood is 680 kg/year (REA, 2007). This does not include wood used for household construction estimated at between .2-.5 odt/year (Buchholz, *et al.*, 2010), or charcoal use (4kg/person/year in rural areas). In Table 10 below, the gasifier's consumption is compared to the current biomass consumption in the Magala village.

As shown in the table below, this system will require only an additional 71 kg of oven dried biomass per person per year compared with the current consumption of 578 oven dried kilograms. This represents a marginal increase of 12% in wood consumption. This value is consistant with other estimations of fuelwood consumption in a small community. Another study calculates a value of .068 odt/year (68 oven dry kg/year) additional biomass required per person per year for electricity generation (Buchholz, et al, 2010). In their study, the firewood consumption for electricity represents a 6.8% increase in additon to the fuelwood consumption already used by the local community for cooking and heating (.5 odt/person/year) and construction (.5 odt/person/year) (Buchholz, et al, 2010).

Table 10: Gasifier Biomass Consumption Versus Current Rural Community Consumption

	Value	***Units/Notes***
Firewood Consumption per Capita per Year	0.680	air dried tons
Assumed Air-Dried Moisture Content of Wood	15%	(Francescato, 2008)
Firewood Consumption per Capita per Year	0.578	oven-dried tons (odt)
Number of Households in the Magala Community	70	from survey
Average Members per Household	8	from survey
Total Population in the Magala Community	560	persons
Total Firewood Consumption in the Magala Community	323.7	odt
Biomass Consumption of the 10 kW gasifier	40	odt
Biomass Consumption of the 10 kW Gasifier as a Percentage of Current Fuelwood Consumption in the Community	**12.4%**	
Additional Biomass needed for the gasifier per capita	**0.071**	**odt**

2.5. Bioenergy Projects and Sustainablity Considerations

2.5.1. Previous and Current Gasification Projects in Uganda

A case study was conducted in 2007 on two biomass gasifiers operating in Uganda, one 250 kW system at the Muzizi Tea Estate in the Kibaale District in Western Uganda, and one 10 kW system operating on a 100 acre farm in Mukono, Uganda. It was shown that electricity from biomass gasification can compete economically with diesel generated electricity when the gasifiers run close to capacity (Buchholz, et al, 2012). This study also found that it was difficult to achieve a stable electricity load close to the rated capacity and that improved business models and a sustainable biomass supply chain are necessary for successful gasification systems.

Another study on the biomass gasifiers in Uganda showed that local tree plantations can reduce emissions by providing biomass gasification electricty over diesel generated electricity, while also avoiding emissions from unsustainable harvest of wood (Zanchi, et al. 2012).

Currently in Uganda, gasification projects are underway through Norgesvel, the Royal Norwegian Society for Development, in collaboration with Husk Power Systems (HPS), a gasification technology provider and operator who has successfully installed and operated gasification projects throughout India.

2.5.2. Modern Bioenergy Projects and Considerations of Scale

Globally, biomass represents a large share of the primary energy consumption of people in developing countries (over 94% in the case of Uganda), espeicially rural areas. In addition, modern bioenergy systems are gaining interest and are increasingly cost competitive compared to fossil fuel sources. In fact, the use of biomass for the production of heat, electricity, combined heat and power (CHP), and transport fuels are increasing worldwide (de Vries et al., 2007).

The UNFCCC generally defines renewable biomass as biomass coming from sources from which land is managed sustainably, there is no steady decrease in carbon stocks over time, and there is no significant land use change (unless land is converted back to forests) (UNFCCC, 2006).

However, in some cases the production of bioenergy is not done in a sustainable manner. Large scale bioenergy projects can possibly have large negative impacts on local social and environmental sustainability. These include competition with food production, disruption of local communities and markets, and negative impacts on natural forest ecosystems and associated biodiversity (Hall, 2000; Reijnders,2006; Sims, 2003)

An important consideration for this project is the issue of scale. In comparing biomass gasifiers of two different scales (200 kW and 50 MW), it was noted that small scale projects are in fact more desirable in terms of sustainability (Buchholz and Volk, 2012). There is a trend to large scale bioenergy projects due to advantages in terms of economies of scale, manageability and control, and certifications. However, this study showed that small scale bioenergy projects have the desired benefits of increased resource efficiency, less impacts on the local environment, and are more likely to directly benefit local stakeholders and community members (Buchholz and Volk, 2012).

One of the ways mentioned to increase the potential adaptation of smaller scale bioenergy projects, is to continue to develop and improve bioenergy sustainability frameworks to allow quick assessments of bioenergy systems in terms of economic, social, and environmental sustainability (Buchholz and Volk, 2012). This thesis aims to contribute to this end.

2.5.3. Criteria and Indicator (C&I) Frameworks for Biomass Sustainability Assessment

The development and use of Criteria and Indicator (C&I) frameworks for measuring progress towards sustainability has resulted from the 1992 report of the United Nations Conference on Environment and Development (UNCED). In this report, the guiding principles of sustainable forest management are presented which cover broad social and environmental concerns relating to the sustainable management of forest resources to ensure their multiple continued benefits to the ecosystem and to the local society. (UN, 1992)

The Food and Agriculture Organization of the United Nations (FAO) defines the C&I Frameworks developed for sustainable forest management (SFM) as ‘tools used to define, assess and monitor periodic progress towards SFM in a given country or in a specified forest area, over a period of time.‘ (FAO,2012). Different C&I frameworks are implemented on national, regional, and forest management unit level in order to assess the conditions of forests worldwide and how well they comply and progress towards the above sustainable forest management principles.

In these frameworks, ***Criteria*** refer to the essential aspects sustainability considered in the management of the forest, for example biodiversity, natural resource management, and rights of the local community. ***Indicators*** refer specifically to the measurable quantities or values which correspond to a certain criterion and can be assessed to monitor the changes and progress of a forest and community (FAO,2012).

Since the 1992 report on SFM, C&I frameworks on the international level have shown progress towards a consistent definition of SFM (McDonald, 2002). Table 11 below shows the shared criteria among three major international C&I frameworks: the International Tropical Timber Organization (ITTO), the European Union (EU), and the Montreal Process (MP). The table lists the number where each criteria is found in the respective frameworks.

Table 11: Comparison between MP, EU, and ITTO C&I Frameworks (McDonald,2002)

Criteria and Indicators	*MP Criteria*	*European Criteria*	*ITTO Criteria*
Conservation of biological diversity	1	4	5
Maintenance of the productive capacity of forest ecosystems	2	3	2 and 4
Maintenance of forest ecosystem health	3	2	3
Conservation and maintenance of soil and water resources	4	5	6
Maintenance of forest contribution to global carbon cycles	5	1	Not included
Maintenance and enhancement of long-term multiple social and economic benefits	6	6	7
Legal, institutional and economic framework for forest management	7	Incorporated in 1-6	1

This C&I framework methodology has been used by a wide range of organizations, standards, labelling and certification boards. Well known examples are FSC and PEFC for sustainable forest management and timber production, as well as many organic agriculture and fairtrade labor standards. The Roundtable on Sustainable Biofuels (RSB) has also recently developed principals and criteria toward the aim of sustainable biofuel production.

In this thesis, the C&I framework methodology will be applied to the available biomass fuel supply options in Pamoja's pilot project. The aim is to develop a sustainable biomass framework in order to investiage the social and environmental aspects, as well as the reliability and costs, of each supply option and to be used for this pilot project and for future gasification and bioenergy projects.

2.5.4. Developing Pamoja's Sustainable Biomass Framework

In order to critically compare and choose the most sustainable biomass supply options for Pamoja's project, a multi-criteria framework has been developed. The framework includes sustainability criteria and standards in order to quantitatively measure the reliability, cost, and social and environmental impacts of the available biomass supply options. This framework has been developed by Thomas Buchholz and the author, Stephen Christensen, during their stay with the Pamoja team in Uganda this spring. This framework draws ideas and inspiration for points to consider from many different sustainable biomass and fair labor standards.

Figure 12: Logos of Notable Standards and Criteria Considered when developing Pamoja's Sustainable Biomass Criteria below shows logos from the notable standards and criteria considered when developing Pamoja's sustainable biomass criteria. From left to right, the standards considered are: **Roundtable on Sustainable Biofuels** (RSB, 2010) ; **Council on Sustainable Biomass Production** (CSBP,2012); **Naturland Standards on Production** (Naturland, 2011), **East African Organic Products Standard** (UGOCERT, 2007) ; **Forest Stewardship Council** (FSC, 1996), **Program for the Endorsement of Forest Certification** (PEFC,2010), **Fairtrade Standards for Timber and Forest Enterprises** (FLO,2011). A list of principles and criteria from the RSB and FSC are presented in Appendix C as an example of the sustainability criteria considered in the paper.

RSB
ROUNDTABLE ON SUSTAINABLE BIOFUELS

COUNCIL ON SUSTAINABLE
BIOMASS PRODUCTION

Naturland

EAC
JUMUIYA YA AFRIKA MASHARIKI

FSC
Forest Stewardship Council®
INTERNATIONAL CENTER

PEFC™
PEFC/01-00-01

FAIRTRADE
INTERNATIONAL

Figure 12: Logos of Notable Standards and Criteria Considered when developing Pamoja's Sustainable Biomass Criteria.

In drawing ideas from the many existing sustainable biomass standards, we see the wide range of considerations for a sustainable biomass supply. These standards consider broad social issues and impacts as well as environmental considerations and ecosystem health

This thesis will attempt to quantitatively assess the considered biomass supplies against each criterion, obtaining a ranking for each supply option and each criteria based on indicators and values taken from literature review.

For example, one environmental criterion commonly considered is assessing the impact on soil quality of implementing a biomass supply or growing trees. This criterion can then be assessed by measuring indiciators such as soil organic matter content, nitrogen and mineral content, and water conductivity, among others. These indicators can either be meausured over time on site or estimated through literature review or calculations.

This framework we have developed additionally considers the reliability and cost of each option as it relates to this gasification project. In considering the reliability and cost of each option, we consider the economic sustainability in addition to the social and environmental sustainability of each biomass supply option.

In this thesis, the developed framework will be tested by comparing the available supply options for Pamoja's pilot project. In doing so, the aim is to help Pamoja choose and implement the biomass supply option which is best for the company, community, and environment, contributing positively to the critieria considered in the framework.

In addition, the effectiveness of this framework in assessing biomass supply sustainability will be discussed. The aim is to improve and adapt this framework for use in future small scale biomass energy projects. In addition, it may be the case that Pamoja would like to have a certified sustainable biomass supply in the future, and this certification will be easier to obtain if Pamoja has already implemented a biomass supply based on similar frameworks.

The framework as it has been developed is presented in the section below, presenting the available supply options considered and the sustainability criteria considered along with a description of what is meant by each criterion.

3. Pamoja's Sustainable Biomass Framework

In this section, the biomass sustainability framework developed by Thomas Buchholz and Stephen Christensen will be presented. This framework first presents all available and suitable biomass supply options including different types of biomass fuel and different management schemes. Next, the framework is presented and the sustainability criteria are presented and described.

Finally, the three most suitable biomass supply options for this piot project will be chosen based on local conditions and considerations. These three options will then be compared against the sustainability framework in the sections following.

3.1. Presenting All Available Supply Options and Management Scheme

The available supply options and management schemes presented here represent the possibilities for current and future projects and include directly purchasing agriculture residues or wood, implementing outgrowing schemes, and buying or leasing land for an intensively managed supply.

3.1.1. Direct Purchase of Biomass from Farmer Cooperatives or Local Markets

Agricultural Residues

As mentioned earlier in section 2.4.4, certain agricultural residues such as maize cobs, groundnut shells, and coffee husks can be used effectively in the gasifier. We can gather and purchase these large quantities of residues from the Magala Growers Cooperative that we work with, as well as from other nearby agriculture processing businesses and purchase the residues directly.

For a long term fuel supply, woody biomass may be preferred due to better fuel qualities and homogeneous fuel compostion, however agriculture residues remain a viable and effective fuel source.

Woody Biomass/Fuelwood

Farmer Cooperatives

Firewood can be bought directly from those farmers in the cooperative which sell their excess firewood. There is a degree of certainty that the wood comes directly from their farms, and in buying this wood, money and value goes directly to the local farmers.

Local market supplier

Firewood can also be purchased from those in the community or nearby villages which sell large quantities of firewood at market price. This adds a degree of uncertainty as to where this wood comes from. Pamoja will not be interested in purchasing wood on the market if there are concerns of deforestation in the area.

Tree Thinnings from Professionally Managed Wood Plantations

Wood for the gasifier can also be purchased from professionally managed tree plantations in the area. During the course of growing trees in a plantation, the trees must be thinned, providing large amounts of excess biomass. Local plantations of the National Forestry Authority (NFA), Sawlog Prodution Grant Scheme (SPGS), or private landowners that are near the project will be identified.

Tree thinnings from plantations can provide significant wood resoures, for example, a 6 year old Pine plantation with a planting density of 1,500 trees/ha can possibly yield about 40 m^3/ha of thinning wood.(Unique, 2006)

3.1.2. Outgrowing Schemes

Outgrowing schemes are a common collaboration in forestry projects between companies and local communities. Outgrowing schemes are partnerships formed when a company communicates and organizes large numbers of farmers in the local community to grow certain agriculutre or forestry products.

Agreements or contracts are made detailing the inputs and support given by the company, the type, quality, and expected production, and final prices to be paid for the product. These agreements can have benefits for both parties if the buisness is conducted openly and fairly. For example companies can gain access to land, labour, and wood products, while communities also can gain access to employment and income, skills, technology and the forest products they grow (Mayers and Vermeulen, 2002)

In this project, we consider implementing outgrowing systems in the form of agroforestry systems and woodlots. Together with Vi-Agroforestry, we can work with the local farmer cooperative and community to grow trees for this gasifier project.

Agroforestry Systems

Agroforestry systems are ‘ the collective name for land-use systems and technologies in which woody perennials are deliberately used on the same land management units as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence.’ (Lundgrem and Raintree, 1992). Agroforestry is a agriculture and natural resource system which is ecologically based dynamic, providing increased land use efficiency, diverse and resilliant agriculture, and increased social and environmental benefits (ICRAF 2006, Kang et al. 1990).

Using agroforestry systems to supply biomass for the gasifier has many benefits in terms of environmental sustainability and benefits to farmers and the community. By incorporating trees into agricultural systems, woody biomass can be supplied to the gasifier while minimizing land competition and food production. In fact, agroforestry systems provide a more resillent agricultural ystemm and provide numerous benefits to farmers, such as fruit, animal fodder, increased productivity with N-fixing trees, and fuelwood (NARO, 2001).

Vi-Agroforestry has an impressive track record in working with farmers to implement agroforestry systems, providing seedlings, training, support and monitoring. By working with Vi-Agroforestry, we hope to implement and expand these beneficial systems while provideing a sustainable fuelwood supply.

Woodlots and Short Rotation Coppice (SRC) Systems on Farmlands or Marginal Land

A biomass supply option commonly used in energy projects is implementing woodlots using Short Rotation Coppice systems. In these SRC systems, trees or shrubs with a fast growth and high production are planted in high densities, typically between 1,000 – 20,000 plants per hectare. The tree species used have the ability to coppice, or to regrow from the same root system after being cut close to the ground and harvested. This maintains a high level of productivity and allows wood to be harvested in cycles typically between 1 and 7 years (Buchholz and Volk, 2007a).

SRC systems provide benefits common with growing trees, including soil conservation, carbon sequestration, and community benefits. In addition coppicing species can also be used in conjunction with agroforestry systems mentioned earlier.

Pamoja aims to avoid interfering with land already used for agriculture, however woodlots using short rotation coppice systems can be started on land unsuitable for farming, such as degraded land or hillsides.

Another possibility is to grow trees on fallow land, implementing improved tree fallows using nitrogen fixing tree species. In starting small woodlots on farms, the species selected must be compatible with the local agriculture. This can provide additional income through selling firewood after the fallow. In adition, soil quality is improved since nitrogen and organic carbon are added to the soil , this improves crop yield over traditional fallows.

3.1.3. Leasing or Buying Land for an Intensively Managed Biomass Supply

Long-term Leasing of Buying of Lands

If leasing or buying of land is a common practice in the community, we can lease/buy the land for an extended time (around 5-10 years). In this case, Pamoja will intensively manage the woodlot. Together with Vi Agroforestry, we will plan and plant seedlings and hire local personnel to maintaining trees and harvesting the biomass.

Another option is to ask to lease farmers' lands for their fallow period, starting improved tree fallows for the duration of the fallow.

3.2. Pamoja's Sustainability Criteria and Standards

3.2.1. Reliability

The fuel supply for this gasifier will be reliably sourced in order to ensure that there is no interruption in supplying the community with electricity. The following considerations on reliability will be taken into account:

Suppliers

There are a variety of options in choosing suppliers for the biomass feedstock, relating to the different management schemes described above. Suppliers such as local farmer cooperatives, private and government landowners, and market suppliers will be considered as potential suppliers.

It is important that we consider the suppliers themselves, the sellers or growers of the biomass, and how they relate to reliability of the biomass supply. It is important to identify primary suppliers while also keeping backup options available.

The reliability of the suppliers will be assessed based on availability or number of suppliers, organizational capacity, motivation, and previous experience.

Supply Dynamics

We also will consider the recent market dynamics of the supply of biomass (agricultural residues and firewood) in the area. Ideally a supply will be chosen with a large and relatively stable market of biomass. This criteria will quantify the amount of biomass available, as well as recent changes or trend in the biomass supply dynamics. For example, considering supply dynamics, any variations in supply between seasons and years will be noted.

Issues for the future supply, such as potential pests, diseases, or impacts from local weather or climate change, such as floods and droughts, will aloso be considered.

Demand Dynamics

Demand In implementing a sustainable biomass supply, it is very important to consider the dynamics of demand in the biomass market. We will take into account recent and projected changes in local deamnd for biomass, as well as changes in population, noting that an increase in population will naturally lead to an increase in demand for wood.

Other important considerations are a growing demand for certain kinds of biomass, for example an increased interest in using agriculture residues for energy production, and the impacts of this demand on availability. We also consider the prices for other markets competing with woody biomass, for example wood for construction, poles, and charcoal. This is an important consideration to avoid side selling to another market of any wood grown for this project

3.2.2. Social Benefits and Impacts

In implementing our biomass supply, Pamoja would like to maximize the social benefits to farmers and the community. With the provision of electricity to the area, there will be benefits to the local society and economy, but we also would like to maximize benefit through implementing the biomass supply.

ValueCreation

Value creation in the community includes additional income, providing local jobs, and other potential benefits. In buying residues or firewood directly from the farmers, the farmers gain a direct income benefit. In outgrowing and leasing schemes, we can provide jobs and hire local farmers to plant and maintain these trees.

Other indirect benefits can reach the farmers through the planted trees and their byproducts. For example, trees used for fuelwood may provide additional fodder for animals or increased crop productivity by using N-fixing trees. The short and long term benefits of agroforestry projects are well documented and in working with Vi, we hope to bring these benefits to the community. Some of these indirect benefits can be difficult to quantify and meausure, so focus will be given to the direct benefits, although indirect benefits will be discussed.

Land Use Competition

Pamoja would like to grow trees for this biomass supply without interfering with current local land use practices and the local food supply. Ideally, trees would be grown in agroforestry systems along benefiting agriculture and the farmers, grow trees on fallow land, or in marginal land unsuitable for crop production. Locations of marginal land will be identified and scouted, noting the potential for growing trees. It is also important to consider and to avoid any competition with wood supplies currently used for cooking, charcoal or construction.

3.2.3. Environmental Impacts

Deforestation and Degradation of Forests

Deforestation is the most serious concern of Pamoja when implementing the bioenergy system and supply chain. It is crucial that the fuelwood supply is sustainable and does not contribute to the rampant deforestation problems already facing Uganda. The current forest cover of the area, recent changes, and deforestation issues will be noted.

Pamoja plans to work together with Vi-Agroforestry and local farmer cooperatives to plan and plant trees to secure a sustainable supply of biomass. It is the hope of Pamoja and Vi that we can mobilize farmers in growing trees, supplying this gasifier, and taking pressure off of natural forests.

Sustainable Farming Practices

Pamoja will encourage the use of sustainable agricultural and silvicultural practices in growing trees. Pamoja will discourage the use of artificial fertilizers and pesticides, encouraging natural alternatives. Pamoja will also encourage the use of other sustainable and beneficial systems such as agroforestry systems, crop rotations and fallows, among others.

Pamoja's NGO partner, Vi-Agroforestry will be important in this aim, as encouraging sustainable farming practices and resillent agriculture through agroforestry systems is their main goal.

Biodiversity

Uganda is very important in terms of biodiversity, and the main concern is to protect the remaining areas of natural forests or wetlands. Any biodiverse lands in the area will be noted and attempts made to protect and conserve them.

Biodiversity will be encouraged on farms and lands growing trees for Pamoja. Polycultural systems with a wide a diverse number of animals, trees, and crops will be encouraged. Large monoculture woodlots, specifically Eucalyptus woodlots, which do not support biodiversity, will be discouraged.

Indigenous (local) species of trees will be encouraged over exotic species, with a special concern on social accpetance of trees planted.. Alien Invasive Species (such as *Acacia mearnsii*) can have a great impact on biodiversity, competing with and replacing the natural vegetation. Species thought to be potentially invasive will be used with great care, or not used at all.

Soil Quality

Efforts will be taken to maintain soil quality in fertile lands and restore soil quality on non-arable or degraded land. Growing trees on degraded lands and hillsides has documented potential to conserve soil, reduce soil runoff, and add nutrients and organic matter to the soil, through N-fixing trees and mulching leaves and branches (Siriri, *et al.,* 2003).

Water Table

Although, research has shown that agroforestry has potential for increasing water use efficiency, there are serious and often underrated implications and considerations for the local water table and balance when planting trees in agroforestry systems or in woodlots.

In implementing a biomass supply, consideration will be given to the current local water supply, taking note of any issues or flooding or droughts. Pamoja will check that the growing of new trees in the area will have little or no impact on the local water supply. A specific concern regarding water is planting trees, especially Eucalyptus, near local wetlands, rivers or lakes.

3.2.4. Cost of Biomass

In addition to reliability, social and environmental considerations, we will choose a supply which minimizes the final cost of the biomass and these costs associated with processing and transport. There are many aspects to consider which contribute to the final cost per ton of biomass. Aspects Pamoja will consider include the market prices and dynamics, processing such as briquetting or sawing, transportation, and storage.

In addition, there may be initial investment or start up costs associated with different supply options, for example, costs for buying or leasing land, costs for tree nurseries, seedlings and other materials. This startup costs will be compared through a net present value (NPV) analysis over the expected project lifetime and will be discounted as applicable.

One intersting consideration is the relation of the final cost of biomass to the price of the electricity generated. Studies on previous gasification projects in Uganda showed that a price of around $22 USD/odt contributes $.03 USD/kWh to the final price of electricity produced (Buchholz, et al. 2012). A case study on modelling this system in HOMER also showed in a sensitivity analysis that a range of biomass prices from $10 -$50/odt produces a range of the cost of electricity produced from $.490-$.549 USD/kWh (Furtado, 2012).

This is only a marginal increase in electricity price due to the increasing cost of biomass.This means Pamoja can possibly pay a ‘premium’ for biomass and in this way, extra money can be spent on ensuring the social and environmental benefits of the biomass used, even if it happens to be more expensive.

3.3. The Three Best Supply Options for this Pilot Project

From the information gathered from the site visits and from everything we have seen, it is clear that currently, the most feasible supply options for this pilot project are **purchasing firewood, purchasing agricultural residues, and implementing outgrowing systems** in the form of woodlots or agroforestry systems.

From our field visits and surveys, we have observed available agricultural residues, especially maize cobs, and fuelwood for sale. We have also seen the organization, motivation, and savings and loan capacity of the communities and farmer cooperatives we work with. We have also seen and heard of the results of successful agroforestry systems implemented by Vi Agroforestry in the whole East Africa region, and we know that outgrowing schemes can be successful in Ugandan communities with appropriate support.

Pamoja has considered buying or leasing land and intensively managing their own woodlots, but now this option does not seem feasible. The farmers that we have interviewed in Magala have told us it is not common to lease their land, only 2 of 16 members in the surveys have indicated that they have ever leased out land.

There are also complicated land tenure issues in Uganda which are a barrier to leasing or buying land to implement a long term supply. The issues arise from colonial legacies, multiple tenure regimes and rights over the same land, and result in tenure insecurity for some of the most vulnerable in Uganda, those dependant on subsistance agriculture (Ministry of Lands, Housing and Urban Development, 2011.

In addition, Pamoja is just now implementing their pilot project and needs to focus their resources and capital on making a successful pilot project instead of leasing/buying land to set up a future biomass supply. The buying or leasing of land to implement our own intensively managed supply is however still an available option for future projects, and should be fully investigated.

These three options of are **purchasing firewood, purchasing agricultural residues,** and **implementing outgrowing systems** will now be compared against the sustainabilit y criteria in the next sections.

4. Purchasing Fuelwood from Local Suppliers

Buying fuelwood directly from the local market or from local farmers is one of the simplest and most straightforward fuel supply options, and the first considered in this framework. Firewood can be bought directly from the farmers in the region with excess firewood, or from bulk suppliers in the local town markets. Below this supply option of purchasing firewood from the market is considered using the sustainability framework mentioned earlier.

4.1. Reliability

4.1.1. Suppliers

For Ugandans living in rural areas, fuelwood is the most common source of primary energy for households (mainly for cooking) and for local small businesses such as charcoal production and brick kilns who consume firewood on a larger scale.

This local demand means that in terms of buying firewood from local farmer cooperatives and the local market, there are currently many suppliers available within the region. We have seen through our site visits that there are vendors selling firewood present in the local community or nearby trading center. In addition, a number of farmers in the Magala village have told us in interviews that they currently have surplus firewood that they sell by the truckload to market vendors and charcoal producers.

In this sense, it is a reliable source of fuel, since for the near future, there will continue to be a demand for firewood and people present in local communities an local markets selling firewood.

4.1.2. Supply Dynamics

There are many strong concerns with the fuelwood supply dynamics. It is the case that there is a growing disparity between the fuelwood supply grown each year and the demand for fuelwood. This growing gap between supply and demand can lead to sharp increases in fuelwood price and puts pressure on natural forests and leads to deforestation of natural forests.

National Supply Dynamics

The FAO 2010 Global Forest Resources Assessment presents data on the loss of forest cover in Uganda since 1990. Based on the numbers presented in Table 12 below, Uganda has lost 1.76 million hectares or around 37% of its forest cover between 1990 and 2010.

Table 12: Reclassified Land Categories in Uganda from 1990 – 2010, (Area in 1,000 hectares) (FAO, 2010)

FRA 2010 Categories	1990	2000	2005	2010
Forest	4,751	3,869	3,429	2,988
Other Wooded Land	1,370	2,377	2,880	3,383
Other Land	13,589	13,464	13,401	13,339

This decrease in forest land fom 4,751,000 ha in 1990 to 2,988,000 ha in 2010, corresponds to a trend in deforestation of just over 88,000 ha/year. The paper also estimates a value of 59.22 ton/ha of above-ground biomass for natural forests. Given these values, we can estimate a deficit of biomass (i.e. consumption – production) of around 5.2 million tons of woody biomass each year.

The CDM Small Scale Working Group (CDM - SSC WG) Meeting 35 in 2012 produced a report (Annex 20) in order to estimate the fraction of non-renewable biomass in annual biomass consumption. By comparing the mean annual increment of biomass grown each year to the total annual biomass removals, an estimate of annual change in living forest and then fraction of non-renewable biomass is calculated. Table 13 below estimates a difference between removal and growth of 6 million tons of biomass. This table also presents the fraction of non-renewable biomass (fNRB) for Uganda as 82%, meaning that 82% of the firewood consumed on a yearly basis is not renewable (UNFCCC, 2012).

Table 13: Calculation for the values of fNRB (Fraction of Non-Renewable Biomass) for Uganda, (UNFCCC, 2012)

F	GR	MAI	ΔF	R	PA	DRB	NRB	fNRB
Extent of Forest (ha)	Growth Rate of biomass (t/ha-yr)	Mean Annual Increment (t/yr)	Annual Change in Living Forest Biomass (t/yr)	Total Annual Biomass Removals (t/yr)	Protected Areas Extent of Forest (ha)	Biomass Growth in Protected Areas t/yr)	Total Annual Removals - Protected Area Growth (t/yr)	fNRB = NRB/(NRB +DRB)
2,968,000	5.65	16,778,846	(6,000,000)	22,778,846	731	4,132,526	18,646,320	82%

As is shown in the table above, the defecit of wood (prouction – consumption) is around 6 million tons yearly. Even though the moisture content of this wood is not stated, and even if we assume the wood to be air-dried at 15% moisture, this still gives a defecit of 5.1 million oven dried tons of wood annually. At a consumption of only 40 oven dried tons annually, this gasification project represents a very small impact on the current national wood defecit situation.

Local Supply Dynamics

In the Magala community interviewed, we have noted that a large amount of families grow enough firewood for their own needs and often sell their excess to market. In considering just this community, the supply seems to be relatively stable, however this is not the case for most of Uganda, as around 50% of rural populations live in areas with a defecit of wood supply. (FAO, 2006). Table 14 below gives the biomass balance (production – consumption) for the rural population of Uganda.

Table 14: Percentages of Rural Populations (<2000 ppl/km^2) in Uganda living under different Biomass Balance Categories, (FAO, 2006).

High deficit	Medium-high defecit	Medium-low defecit	Balanced	Medium-low surplus	Medium-high surplus	High surplus
21.8	24.5	3.6	2.5	3.7	28.7	15.3

The FAOs WISDOM publication 2005 gives information on the balance of supply and demand balance for 5 arc minute cells (or 9km x 9km squares) for East Africa. The map of the supply-demand balance for Uganda is given in Figure 13 below alongside a google map showing the GPS location of the Magala village.

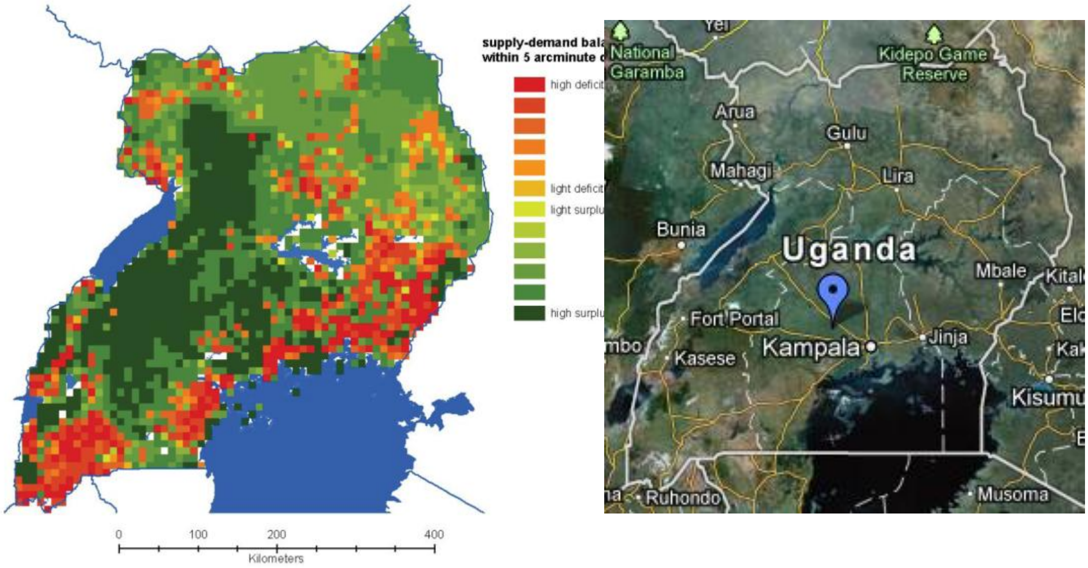


Figure 13: Maps of Uganda showing biomass balance (left), (FAO, 2006), and Google Maps Image showing the location of the Magala village (right), (GPS, .52803 N, 32.13436 E).

In overlapping these two maps we can get an idea of the local balance in the surrounding area. This map, shown in Figure 14, shows that our village in general is located in an area with a medium to high surplus of woodfuel. This is consistant with the information we have gathered in interviews from the village where they have indicated that it is common for those in the community to grow excess fuelwood and sell it in bulk.

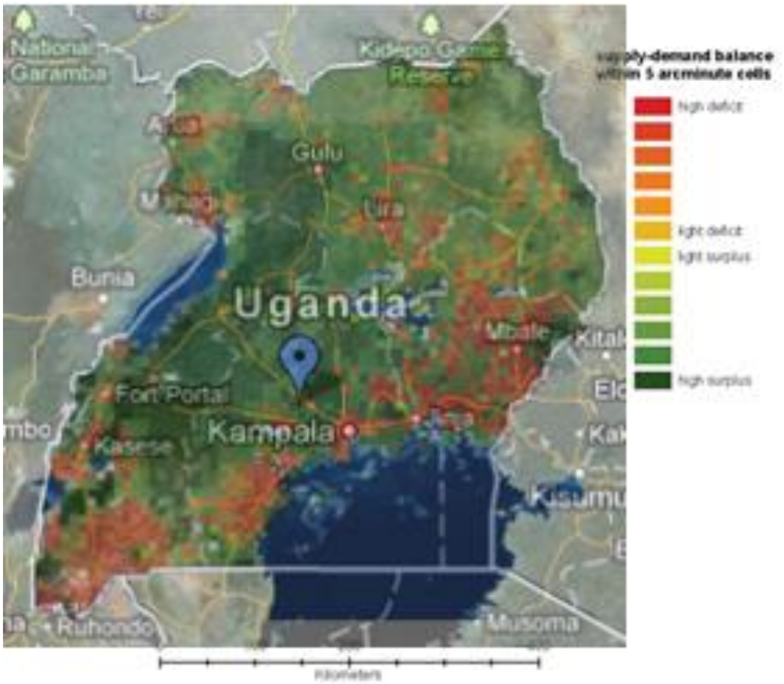


Figure 14: Overlapped image of the two separate maps above in Figure 13, showing that in general the Magala village is in an area with medium biomass surplus.

4.1.3. Demand Dynamics

Firewood Demand

The demand for firewood continues to grow as the population grows, since as mentioned earlier, fuelwood is the primary energy supply for the majority of Ugandans. The demand therefore will continue to grow for fuelwood. Nationally, the growth in charcoal demand is around 6% per year, or basically matching the rate of urban population growth (Ferguson, 2012). If the growth in firewood demand is typical of this trend, then the estimated rate of growth in firewood demand will match the rural population growth, or 3% per year (World Bank, 2012).

There are many other measures and programs involved in reducing firewood demand, such as energy conservation programs and programs to introduce more efficient cook stoves. Currently however, only 8.5% of households use improved wood stoves (UBOS, 2010). The REA outlines in their strategies an obejctive of increasing the adoption of improved stoves from 170,000 households as of 2007 to 4,000,000 households by 2017 (REA, 2007).

This growing gap in supply and demand and the recent dynamics suggest that the cost of firewood will continue to rise and directly purchasing firewood is a possibly unstable long term solution.

4.2. Cost

In our meeting and survey with the Magala Growers cooperative, they said that it is common for local farmers to sell their excess firewood that they have available from trees grown on their land. This wood is normally sold to bulk suppliers in the local town market, but the community said they would be willing to sell their firewood to Pamoja to contribute to electricity generation in the community. The community members sell excess wood at a price around 70,000 UGX - 120,000 UGX per truckload (truck shown below in Figure 15).

Figure 15: A blue truck commonly used for transport in Uganda.

Based on this price and from truck measurements taken during the field visit we can get an approximate price for purchasing firewood by the truckload based on the calculations in Table 15.

Table 15: Calcualtions for wood price ($USD/odt) in the Magala village, based on values from field visits.

	Value	***Comments***
Price per truckload UGX	70,000 UGX - 120,000 UGX	from general survey
Price per truckload USD	$28 - $48 USD	currency conversion
Truck Bed Volume Measurements (l x w x h)	3.1m x 1.6 m x 1.1m	from field measurements
Total Truck Bed Volume	5.456 m^3	
Basic Wood Density*	495 kg/m^3	*defined as oven dried mass over green volume, assuming Eucalpytus wood (Bhat, et al, 1990)
Void Space of Stacked Firewood	50%	(Francescato, 2008)
Total Mass of Wood in the truck bed	1,35	odt (oven-dried tons)
Cost per oven-dried ton of wood	**$20.8 - $35.5 USD/odt**	**odt (oven-dried tons)**

This value range of $20.8 – $35.5 USD per dry ton is consistent with values seen in other biomass projects and in literature.

A study on the agronomic and economic potential of tree fallows in southwest Uganda obtained values for the price of wood for the cost-benefit analysis. Wood from the experiment was sun dried for 3 months then farmers in the area were asked to determine the price of the wood at the farm gate (not including transport/other markups). Table 16 presents the range of prices determined in the study.

Table 16: Farm gate price for wood outputs in southwest Uganda (Siriri, *et al.*, 2003)

Wood Outputs	Cost ($USD/kg)
Sesbania wood	.038
Calliandra wood	.031
Alnus wood	.033

Assuming this wood is completely dry, since it was sundried to a constant weight, gives a price range per oven dried ton of $31 – $38 / odt, roughly in the same range as earlier estimates.

Recent Changes in Fuelwood Price

In checking how the price for fuelwood has changed recently, we can check the Consumer Price Index Reports produced by the Uganda Bureau of Statistics (UBOS). Data available on the UBOS website gives prices for fuelwood in the capital city of Kampala, based on the Consumer Price Indicies (CPIs) for the past 3 years. Figure 16 below presents the data gathered from the UBOS website, makring some months.

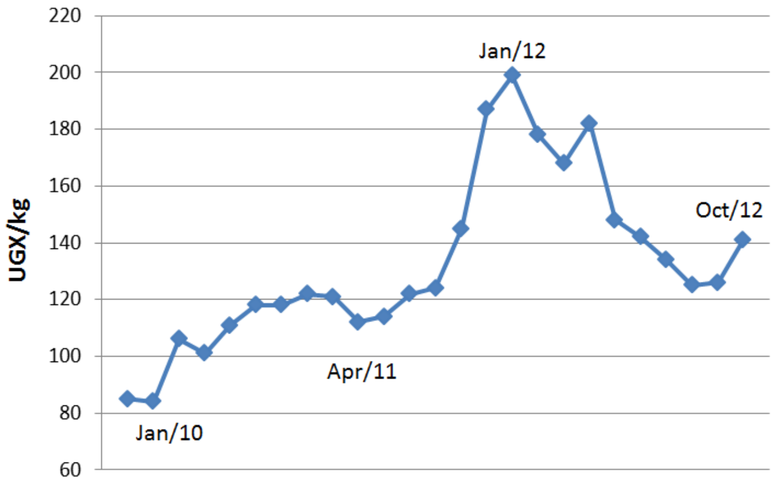


Figure 16: Firewood prices in Kampala in UGX/kg from Dec 2009- Oct 2012 (UBOS, 2012)

Based on the CPI, we see the increase in firewood prices in just the past 3 years. The latest price given is 141 UGX or .0564 USD per kilogram. This gives a price of $56.4 USD per ton, however this is the price for wood in the capital city of Kampala, which should be more expensive than in rural areas. Moisture content is also not considered here, this is just to illustrate the recent inreases in price.

4.3. Social Impacts

Purchasing firewood directly has very minimal social impacts both in terms of value creation and land use competition.

4.3.1. Value Creation

The new value creation coming from directly purchasing firewood is minimal. In buying firewood from bulk suppliers and from farmers, we do not create any new value, as the firewood we purchase would otherwise be used or sold as usual.

4.3.2. Land Use Competition

Due to the scale of our project compared to the community's present firewood usage and the fact that there is a surplus of firewood in the community, it is very unlikely that purchasing firewood for this project will have an impact on land use change or competition within this village.

4.4. Environmental Impacts

In the case where firewood is bought directly from the town markets, we are ultimately unsure of where this firewood comes from, leading to many environmental concerns we cannot quantify. In the case where firewood is bought directly from the farmer cooperative, we can be relatively certain the wood comes from the local area and can therefore comment on local environmental impacts.

Leakage Concerns

An important consideration for environmental impacts (and social impacts also) that should be mentioned is the concern over impacts in other areas, known as leakage. Leakage is typically connected to carbon dioxide emissions. Carbon leakage on a project basis is defined as 'the unanticipated decrease or increase in greenhouse gas benefits outside of a project's accounting boundary resulting from the project's activities.' (Schwarze, *et al.*, 2002).

In bioenergy and forest based rojects, the two most common negative leakage impacts are activity-shifting leakage (i.e, people leaving a project area to go cut trees elsewhere) or market leakage (less wood available due to the project, more pressure to cut elsewhere) (Schwarze, *et al.*, 2002). In considering this community, the most likely source of leakage is market leakage.

An example of considering leakage effects can be used for the environmental impact of deforestation. The surplus firewood available within the Magala community is now currently being sold to bluk suppliers and large scale consumers such as brick kilns and producers of charcoal. In buying wood from the local farmer cooperatives, we will take away 40 oven-dried tons of wood from other suppliers, who will then have to find their wood from other sources.

Leakage effects are important to consider, even at this small scale. Possible concerns of leakage will be noted in the appropriate criteria for each fuel supply option.

4.4.1. Deforesation and Degradation of Forests

In terms of the local surroundings of the Magala village, there are no natural forests remaining which are under threat. The Magala village surroundings are mainly households practicing subsitance agriculture, along with some hillsides and scattered trees.

However, in looking at the local forest reserves in the Mityana district and in the Sekanyonyi sub-county, we can see pressure on a number of forests reserves. A news article recently describes the eviction of over 600 encroachers who have been using forest reserve land in order to grow maize and vegetables. The forest reserves mentioned in the article are Kassa, Kajonde, Musamya, Mukambwe, Walugondo and Bulonda. (Muzaale, 2012).

The article above describes forest reserves that are in the entire Mityana district. The Magala village is located in the Sekanyonyi sub-county, as shown as a sub-county on the map of the Mityana district below.

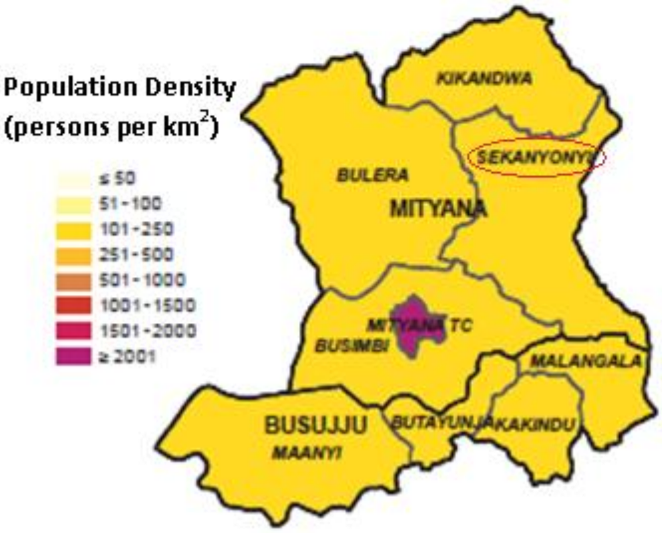


Figure 17: Population Density Map of the Mityana District, with the Sekanyonyi sub-county circled in red (map from Ministry of Water & Environment, 2010)

Table 17 shows forests near the Sekanyonyi sub-county, as gathered from google maps, through a travel website (TravelsRadiate, 2012). Two of these forests listed here, the Kassa and Kajonde forests are also mentioned in the article on encroachment above.

Table 17: Forests near the Sekanyonyi sub-county (TravelsRadiate, 2012)

Forest Name	*Distance from Sekanyonyi (km)*
Wamango	25.2
Tumbi	19.6
Towa	23
Kasa	25.3
Kajonde	19.5

In buying firewood directly from the local market, we are ultimately unsure of the origin of the wood. The wood could come from professionally managed plantations, local farmers, or from local natural forests such as those listed above. This uncertainty leads to concerns that we could be buying wood directly taken from natural forests and expanding on the problem of deforestation.

Buying firewood from the Magala community means that we are relatively sure of its origin and that it does not contribute to deforestation in the area.

However, as mentioned in the example in the section above, there is a possible concern of market leakage outside the project boundary. In using this wood that would have previously been sold outisde the community, the previous buyers of wood will now have to find another source for wood. This can lead to increased pressure on forests or woodlands and deforestation in other regions outside of our project's consideration.

Due to the small scale of this first pilot project compared to the firewood market and since our community has a surplus of firewood, leakage effects will not be large or a crucial consideration at the moment. However, it may become be an important consideration in Pamoja's future projects and up-scaling, however.

4.4.2. Other Environmental Impacts

The other environmental impacts considered in the framework, such as Sustainable Farming Practices, Biodiversity, Soil Quality, Water Table, will not be considered in this section. For local market suppliers, we can not comment due to the uncertain nature of the firewood's origin. For the local area, there will be no net change for these impacts in the local area, as the excess wood is already being cut and sold .

Even at a small scale, this project still adds to the growing difference between firewood that is produced and firewood that is consumed. Therefore this supply option is considered, however it is not in the interest of Pamoja and their focus on a sustainable biomass supply.

5. Purchasing Agriculture Residues

The second of the most feasible supply options is the option to buy agricultural residues straight from local farmer cooperatives or from local agriculture processing plants, the most common being maize mills and shelling or husking plants for groundnuts and coffee.

As mentioned earlier in the paper, certain agricultural residues are better than others in terms of fuel quality. The best agricultural residues in terms of fuel quality and availability in this community are **maize cobs, coffee husks,** and **groundnut shells**.

Groundnut shells are a preferred fuel over the other residues since they have suitable dimensions, low moisture content and better performance in the gasifier. However, there is limited information from our surveys on their availability in this community, so instead a conservative estimate will be made on the availability of groundnuts. This section will also focus on the availability of maize cobs and coffee husks in the Magala village.

We will investigate the potential and impacts of each of these residues by considering the options against the framework in this section.

5.1. Reliability

5.1.1. Suppliers

We plan to source agriculture residues through suppliers in the local community which aggregate these residues. We plan for our primary supplier to be the Magala Growers Cooperative, as we are working with them on this pilot project and the gasifier will be installed next to their maize processing machines.

We consider the Magala growers cooperative to be a reliable supplier, as we have seen their motivation, and they have proved their capacity in community savings and loans, and in organizing and growing their business. They have recently generated 16 million UGX ($6400 USD) in savings in the past 7 months. They also have shown us their projected harvest records based on previous seasons yield.

With support from the NGO Vi-Agroforestry, one of Pamoja's partners in this project, the Magala Farmers Cooperative successfully implemented agroforestry systems. Vi now has left the area after the successful implementation and maintains contact with the cooperative. With additional support from Vi-Agroforestry, the Magala Growers Cooperative was able to purchase a maize milling machine and now runs a successful business.

Their past experiences and motivation shows their reliability as an organization and their potential to supply agriculture residues for the gasifier. This measure of reliability and motivation was one of the determining factors for Pamoja in selection of the Magala Village for the site of the pilot project. Their organization, motivation and stable supply of agriculture residues, along with the fact that we will be working closely with them as partners, leads us to consider that they will be a reliable primary supplier.

Backup supply options for agriculture residues will include other nearby farmer cooperatives, and cooperative or privately run agriculture processing businesses. These suppliers will potentially have large quantities of agriculture residues available for sale. During our site visit we have noticed many local farmer cooperatives and agriculture processing plants, but unfortunately do not have direct values on their numbers or locations.

5.1.2. Supply Dynamics

National Supply Dynamics

At a national level, we can see records from the past few years to get an idea of any changes in production and yields over the past few years.

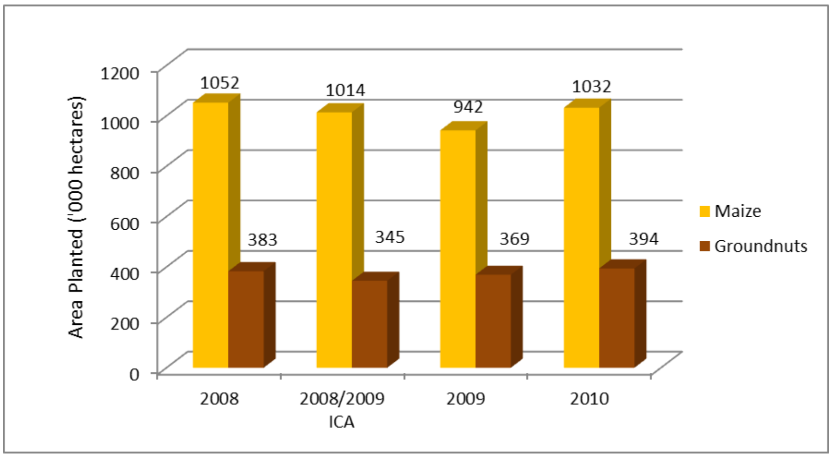


Figure 18: Area Planted (in '000 hectares) for Selected Food Crops, Maize and Groundnuts, from 2008-2010 (UBOS, 2011a).

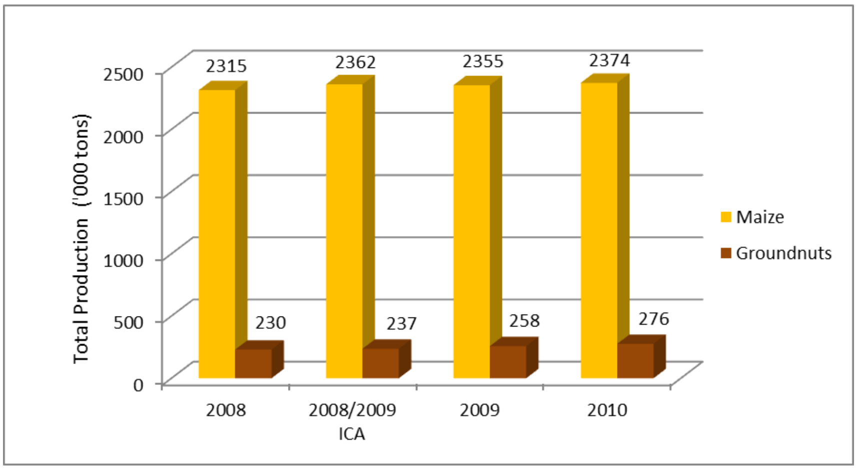


Figure 19: Production (in '000 tons) of Selected Food Crops, Maize and Groundnuts, from 2008-2010 (UBOS, 2011a).

Table 18: Productivity (in tons/ha/year) for Selected Food Crops, Maize and Groundnuts, from 2008-2010, as calculated from the figures above.

Yield for Selected Food Crops (tons/ha/year)	*2008*	*2008/2009 ICA*	*2009*	*2010*
Maize	2.20	2.33	2.50	2.30
Groundnuts	0.60	0.69	0.70	0.70

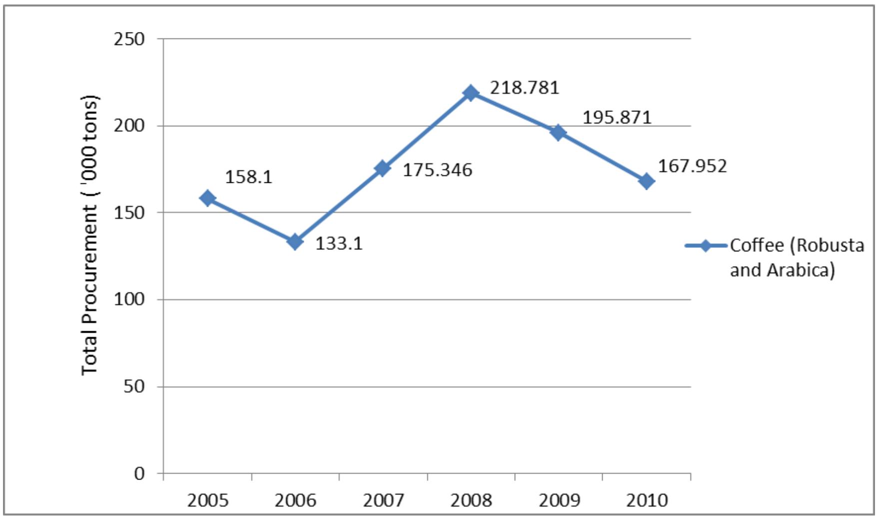


Figure 20: Total Procurement (in tons) of Main Cash Crops, Coffee (Robusta and Arabica), from 2005-2010 (UBOS, 2011a)

These graphs and tables show the total agricultural production and yields of selected food crops, and the total yearly production of coffee. As is shown in Figure 18,

Figure 19, and Table 18: Productivity (in tons/ha/year) for Selected Food Crops, Maize and Groundnuts, from 2008-2010, as calculated from the figures above. Table 18, the total production and yields for Maize and Groundnuts have not varied largely in the years 2008-2010, while Figure 20 shows the production of coffee has varied greatly in the years 2005-2010, from a low production of 133,100 tons in 2006 to a higher production of 218,781 tons in 2008.

Regional Supply Dynamics

In checking the records on a regional level, the records available are from the 2008/2009 Uganda Census of Agriculture (UCA) which provides many precise figures on the production of agriculture food crops in Uganda. Figure 21, Figure 22, and Table 19 in the next page presents the data from the 2008/2009 UCA for the Mityana district as given in UBOS, 2011a.

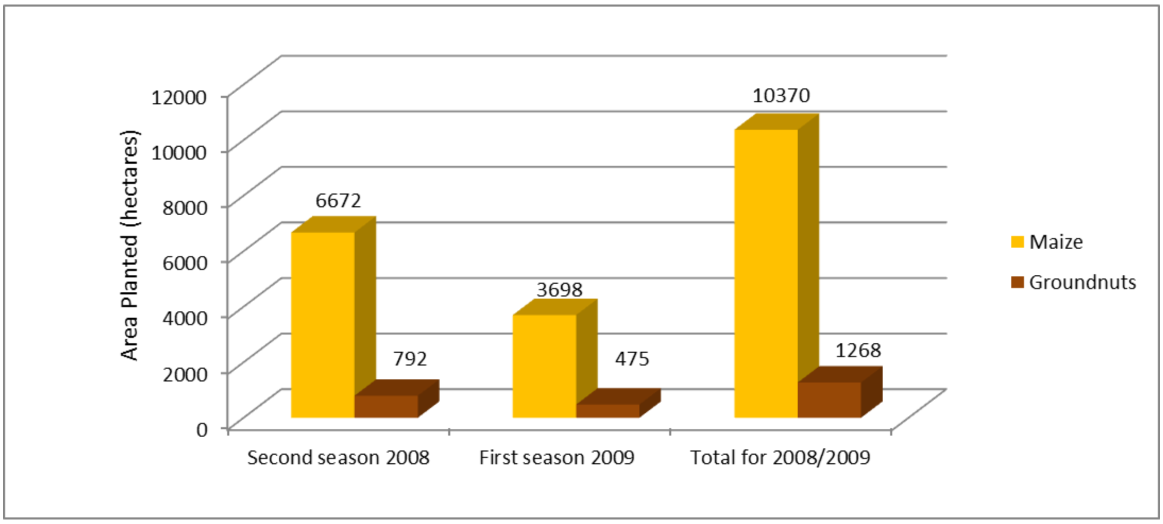


Figure 21: Area Planted (in hectares) for Selected Food Crops, Maize and Groundnuts, in just the Mityana District from the 2008/2009 UCA (UBOS, 2011a)

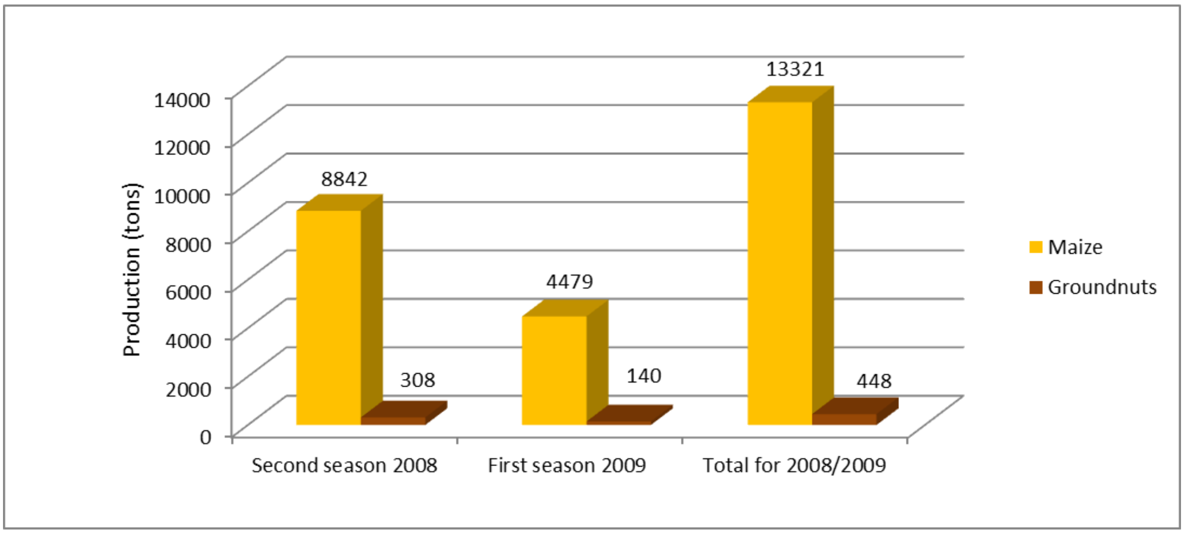


Figure 22: Production (in tons) for Selected Food Crops, Maize and Groundnuts, in just the Mityana District from the 2008/2009 UCA (UBOS,2011a)

Table 19: Productivity (in tons/ha/year) for Selected Food Crops, Maize and Groundnuts, in just the Mityana District from the 2008/2009 UCA (UBOS,2011a)

Yield for Selected Food Crops (tons/ha/year)	2008	2008/2009 ICA	2009
Maize	1.33	1.21	2.54
Groundnuts	0.39	0.29	0.68

The productivity in the Mityana region as shown in Table 19 table above is right around the national productivity levels as given in Table 18 above.

Another important thing to note is the potential difference in production between the first and second seasons as shown in Figure 21 and Figure 22 above. This is different from the assumptions made in the earlier estimates at the village level and is important to consider in maintaining a reliable fuel supply.

Local Supply Dynamics

The supply of agriculture residues available in Sekanyonyi ultimately depends on the agriculture yield in the area, which depends on many complex interactions between the weather, the farmers, their practices and farming systems, and soil health. In order to get an idea of the recent yields in the community, we have conducted a baseline survey of the Magala community. We can then compare these to regional and national production records. Unfortunately, no records were currently available from this farmer cooperative, however they did have projections for the next season based on an assumed productivity.

In this region of Uganda, there are two main growing seasons for crops, as opposed to the drier north which has only one growing season. The timing and duration of these seasons are shown in Figure 23 below. It is importatnt to consider the seasonality of the crops and therefore residues for the fuel supply. The Magala Cooperative has told us that they will soon build a storage shed for their maize in order to have a year round supply of maize and maize flour. It is possible for us to build this storage together and have a space for storing residues as well.

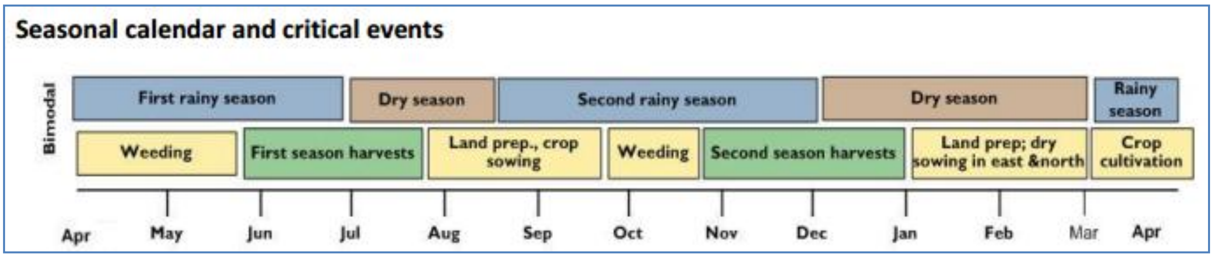


Figure 23: Seasonal Calendar and Critical Events of the Bimodal Growing System in Uganda (USAID, 2012)

The Magala Growers cooperative has certain requirements for its cooperative members to each grow at least 1000 kg of maize per season, 500 kg of which is to be made into flour at the maize mill and sold. The cooperative also requires the members to produce at least 300 kg (5 x 60kg bags) of coffee each season; although they say on average they harvest 600 – 900 kg (10-15 x 60 kg bags) of coffee each season. Unfortunately no data was available from the cooperatives on the production of groundnuts. From the general meeting and discussions with the Magala community, they have said that these minimum requirements are met by each member, and are often exceeded.

Table 20: Production of Maize and Coffee in the Magala Growers Cooperative and amount of Residues Available per year in oven dried tons. (Moisture Content and RPR taken from Table 7)

Number of Active Cooperative Members	***250 Members***	
Agriculture Product	**Maize**	**Coffee**
Amount Produced Each Season per Member	1000 kg	600 kg
Amount Brought to the Mill per Member	500 kg	300 kg
Total Quantity Produced Each Season	250 tons	150 tons
Total Quantity Brought to the Mill each Season	125 tons	75 tons
Residue to Product Ratio (RPR)	0.27	2.1
Total Residues Potentially Available per Season	53.15 tons	101.61 tons
Total Residues Brought to the Mill per Season	26.57 tons	50.80 tons

Moisture Content of Residues	7.5%	15%
Total Residues Brought to the Mill per Year	**49.16 odt**	**86.37 odt**
Total Residues Potentially Available per Year	**98.33 odt**	**172.74 odt**

From the baseline study conducted by the Pamoja team in the Magala community, a baseline analysis report was written. The survey of the maize production of 16 farmers in the area was extrapolated to include the number of farmers along the road within 1 km (86 households). The report estimates the maize production and maize cobs available in Magala per season and year, and the results are summarized in

Table 21.

Table 21: Estimate of Maize Cobs Available in Magala from the Pamoja Baseline Report (Pamoja, 2012)

	Maize	Maize Cobs
Total for 16 Farmers per growing season	24,630 kg	4,926 kg
Extrapolation for 86 farmers per growing season	132,386 kg	26,477 kg
Total Maize Cobs Available in Magala for 1 season	**-**	**26.48 odt**
Total Maize Cobs Available in Magala for 1 Year (2 Seasons)	**-**	**52.95 odt**

Although this value of 52.95 tons is obtained by a different methodology, it is close to the estimate of the available cobs brought to the maize mill each season as shown above in Table 20. Also these are just the households along the road within 1km. There are other households farther off the road and outside of 1km, and it is also possible to source residues from them.

Problems Affecting Crop Production

In our survey, we have asked farmers if there were any problems that have recently affected their crops (Figure 24). These problems are quite common in agriculture and can be managed by certain agricultural practices, fertilizers, pesticides and improved water management systems. However, despite these issues, the farmers in the Magala community still report continued successful yields and harvests.

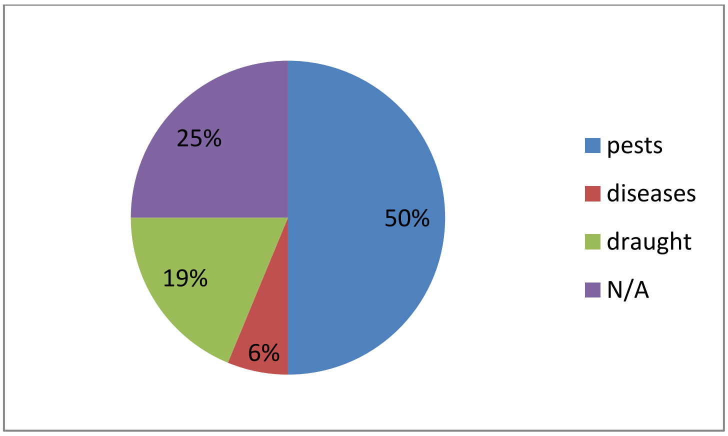


Figure 24: Recent Problems Affecting Farmers in Magala, from Pamoja's Baseline Survey (Pamoja, 2012)

Climate Change and Potential Impacts on Agriculture

Another concern for this community and for all of Uganda is the impacts that climate change will have on crop yield. A investigation on the impacts on crop yield in Uganda predicts that crop yields will decline by 10%-50% under projected climate change scenarios. In additon, climate change will intensify the hydrological cycle, leading to an increase in rainfall of about 10%-20% by 2080. Any gains in increased rainfall, however, will be offset by higher temperatures and soil evaporation. Variability in growing seasons, periods, and weather patterns will also become more common. (Wasige, 2009)

Climate change is a global issue that can have a major impact on the sensitive and necessary areas of agriculture and food production in Uganda. According to a report by the Intergovernmental Panel on Climate Change (IPCC), all of Africa is likely to warm at a rate faster than the global average, but Africa is also the continent that is least likely to cope with climate change. The paper outlines some of the future impacts on different aspects of the local environment and society in Uganda, as given in Table 22.

During our trip it was noted that the rainy season that was supposed to start in the middle of March started in the middle of April, almost 1 month late.

Effects from climate change can already be seen in Uganda with an increase in the amount of droughts per decade. It is still uncertain how this will impact the people of Uganda and agricultural production, however there are mitigation and adaptation programs being implemented at local and national levels in Uganda (Corner, 2011).

One of the main goals of our NGO partner VI-Agroforestry, is to implement and promote sustainable and diverse agriculutre systems that will be resillant against the variability brought by climate change. In partnering with Vi and working with this community, we increase the transfer of knowledge and implementation of resillant agriculture systems.

Table 22: Climate Change Impacts Relevant to Water and Agriculture Production in Uganda (Corner, 2011)

	Impact	*Mechanism*
Water	Change in river flow regimes	Higher temperatures and melting of the Rwenzori glaciers temporarily increase then reduce flows in the Semiliki river downstream.
	Water scarcity	Higher temperatures, evaporation and recurrent drought leading to stress, higher demands for water, conflict, and bio-diversity loss.
	Flooding	High mean and increased intensity rainfall, coupled with land degradation and encroachment raises risks of loss of life and property and damage to infrastructure via flooding.
Agriculture and Food Security	Higher average rain-fall, high intensity events	Crop damage and soil erosion
Environment	Land Degradation and Deforestation	Higher forest fire risk in dry periods; pressure on forests when other livelihood assets collapse; salination and soil erosion

	Species Extinctions	As niches are closed out by shifts in climate change
Economy	Food Prices	Increases due to pressure on internal and international production capacity.

5.1.3. Demand Dynamics

National Demand for Agriculture Residues

Demand for agriculture residues as an alternative fuel source will increase on a household level as population and energy demand increase and as fuelwood becomes less available and more expensive. On a larger scale, demand for agriculture residues will increase as fossil fuel prices and energy demand rises, and more biomass energy generation projects are implemented.

Projects that have been implemented or are in the planning stages include a 50-MW biomass energy plant (Biopact,2012), 40 MW, Municipal Solid Waste gasifier in Kampala (Waste Management World, 2011), Briquettes from crop waste (Ferguson, 2012), and pilot biomass energy projects funded in Uganda (Devex,2009) , among others. In addition, great attention is now being paid to the potential of agricultural residues for energy use (MEMD, 2001).

Local level demand for Agriculture Residues

Currently there is a slight demand and use for certain agriculture residues. Maize cobs are commonly used in the Magala village for cooking in place of firewood or charcoal. The results from a survey of the Magala community (16 households) showed current uses of agriculture residues, as shown in Figure 25.

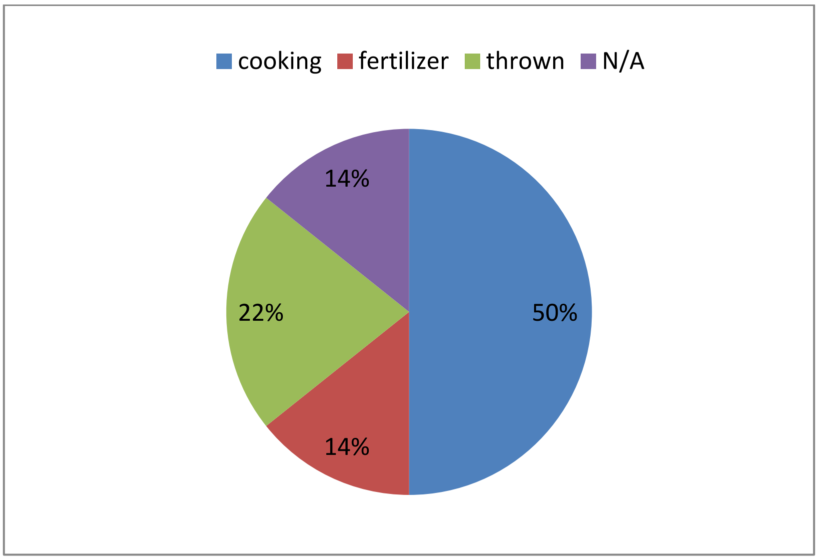


Figure 25: Responses from the Magala Village on current usage of agriculture residues.

This estimate of around 50% of residues being used for cooking is consistent with a study conducted by the MEMD (2001) , which estimated that only 50% of crop residues available for energy purpose are consumed.

Even if we assume that only 50% of maize cobs are already used for cooking, this still leaves at least 49 odt of maize available per year just in the Magala village. This is just enough to cover our demand of 40 odt/year.

We have also seen on our site visits that coffee husks are ocassionally used to cover the ground of chicken houses or as a fertilizer. Assuming 50% of these residues are also available, this leaves us just over 86 tons of coffee husks available per year in the Magala village.

It is also possible to take residues from other nearby villages outside the Magala village. There are many other farmers and cooperatives in the surrounding areas in the Sekanyonyi district. In addition, more residues will be potentially available if we offer to buy the residues at a price attractive to farmers.

5.2. Cost

A study from the Iowa State Department of Agronomy calculates industry prices for maize cobs in the US to be between $30 and $50 per odt. (Jansen, *et al.*, 2011). This is on the high side of the desireable fuel price range, however this is in the US. There is unfortunately no data available on the prices for maize cobs sold in Uganda, perhaps since it is not a common practice.

On our site visits, we have noted that large bags of coffee husks are typically sold for around $3 USD (7500 UGX). A team from engineers without borders working on a biomass charcoal experiment in Uganda reported buying a 50kg bag of dry coffee shells for $1.50 (Patrick, 2009). This range of $1.50 to $3 USD for 50kg of coffee husks gives a range of $30-$60 USD per odt of coffee husks.

Another consideration is to pay for agriculture residues based on the heating value of the residues themselves. Common values for the higher heating value (HHV) of wood are between 18.5-19 MJ/kg.

In taking the HHV of wood and the values of around $20-$35 USD/odt that we expect to pay for fuelwood, we can estimate price ranges for agriculture residues, based on their higher heating values (HHVs). Table 23 below gives the higher heating values of the agriculture residues we consider for use in this pilot project.

Table 23: Heating Values of Suitable Agriculture Residues and Prices Ranges Adjusted to Match the Heating Value of Wood (HHV of residues taken from Table 8)

Residues	*Maize Cobs*	*Coffee Husks*	*Groundnut Shells*
HHV (0% moisture)	16.28 MJ/kg	16.08 MJ/kg	17.89 MJ/kg
Residue HHV/Wood HHV (18.5 MJ/kg)	.88	.87	.97
Adjusted Price range for residues (from $20-35$ USD for wood)	$17.6 -$30.8 USD	$17.4-$30.4	$19.3-$33.8 USD

Since the Heating Values of these selected residues are all similar and only slightly less than firewood, they all have similar expected price ranges, around $17 - $34 USD /odt.

5.3. Social Impacts

5.3.1. Value Creation

Purchasing agriculture residues directly from farmers or farmer cooperatives can have a direct and positive monetary impact. If the residues that we buy were not being used before as a fertilizer or fuel, this creates a new source of value and income for farmers.

Assuming that a farmer meets the production requirements of the Magala cooperative, 1000 kg of maize and 600 kg of coffee per season, or 2000kg of maize and 1200 kg of coffee per year, the additional value from selling these residues can be calculated. The additional value from selling an esimtated 50% of the available residues produces is calculated and shown in Table 24 below.

Table 24: Estimated Agriculture Production of a Farmer in the Magala Village and Calculations on Added Value from Selling Residues.

Residues	*Maize*	*Coffee*
Production per person per year	2000 kg	1200 kg
RPR	.27	2.1
Residues Available per year	425 kg	813 kg
Moisture Content of Residues	7.5%	15%
Residues Available per year (oven-dried biomass)	393 kg	691 kg
Total Residues Available per year	1084	
Currently Unused Residues (assuming 50%)	**542 kg**	
Average Value of Residues ($/odt)	**$25**	
Additional Value created ($USD / person/year)	**$13.55**	

Values for the monthly income of farmers in rural Uganda can vary widely based on location, crops, harvests, and seasons. However, an average value given is 70,000 UGX/month ($28 USD/month), (Kossov, 2009)

If we take the value of 70,000 UGX/month ($28 USD/month), then the additional value created of $13.55 USD/year is about equal to about half a month of additonal income.

5.3.2. Land Use Competition

Using residues from agriculture products does not directly contribute to land use competition as we will only use the residues available from the agriculture practices already underway.

5.4. Environmental Impacts

Not much can be said regarding the environmental impacts of using agriculture residues as a fuel supply. By the time we buy the agriculture residues, any environmental impacts from growing the crops have already been realized.

We can however by working with local NGOs, especially our partner Vi – Agroforestry and the Magala cooperative, make additional information available about sustainable agriculture practices and implement more sustainable systems.

5.4.1. Deforestation and Degradation of Forests

In using agriculture residues for fuel for this gasifier, there will be no direct impact on deforestation of natural forests in the area. If we take some of the maize cobs that were previously used for cooking, then there is a possible impact in that people will have to use another source for cooking, possibly firewood. As mentioned in the firewood section, there will be no direct impact in taking extra wood from the local area since there is a surplus. However, there may be concerns of carbon leakage, affecting areas outside of this project.

5.4.2. Sustainable Farming Practices

Although impacts from agriculture will already be realized for the first rounds of residues we use, we can work together with the farmer cooperatives and with Vi-Agroforestry to disseminate knowledge and encourage farming practices that are more sustainable and possibly lead to greater crop yields.

5.4.3. Biodiversity

There will no impacts on local biodiversity from using agriculture residues for this project. There are possible leakage effects to consider outside of the project area due to natural forests being cleared for wood and agriculture land, however this effect is not large in this project.

5.4.4. Soil Quality

Impacts on soil quality from using these agriculture residues will be minimal. The residues we consider are process residues, meaning that they are left over after agriculture processing, as opposed to field residues which are residues of the crop which are not harvested and are typically left on the field. As we have seen in our visits, the process residues are frequently left over in big piles near the processing machines and are often not brought back to the fields.

The amount of organic matter and nutrients that are taken from the soil by using agriculture residues are relatively small compared to the whole crop and since the residues are commonly not brought back to the field, this has no more long term impact on soil quality than the harvesting of the crop itself.

Even so, an example showing the relatively small impact on soil quality from the harvesting of maize cobs is provided in the section below.

Organic Matter and Nutrient Removal From Using Maize Cobs

Research conducted at Iowa State University gives the dry matter and nutrient composition of each component of the entire maize crop. Based on information in Table 25 below, harvesting the grain, or the maize itself, takes 47.6% of the organic matter off of the field. Harvesting cobs for use in the gasifier will take away an additional 7.5% of the organic dry matter, leaving the rest of the maize stover, or 44.9% of the organic matter on the field.

Table 25: Organic Matter and Mineral (N,P,K) Content of Different Components of the Maize Plant (Sawyer, *et al.*, 2007)

Component	*Dry Matter*		*Nitrogen*		*Phosphorus*		*Potassium*	
	% of total	lb/acre	% N	lb N /acre	% P2O5	lb P2O5 /acre	% K2O	lb K2O /acre
Grain	47.6	1413	1.44	20.42	0.69	9.75	0.5	6.99
Cobs	7.5	223	0.33	0.74	0.11	0.24	0.62	1.38
Stalks	22	653	0.43	2.76	0.14	0.92	0.9	5.89
Leaves	10.6	315	1.8	5.70	0.69	2.21	2.05	6.44
Sheaths	5.3	157	0.64	1.01	0.37	0.59	1.74	2.76
Husks	4.3	128	0.36	0.46	0.21	0.28	1.32	1.69
Shanks	1.5	45	0.5	0.22	0.18	0.07	1.68	0.75

Tassels	0.5	15	0.97	0.15	0.5	0.07	1.7	0.26
Lower ears	0.5	15	2.04	0.29	0.87	0.13	3	0.44
Silks	0.2	6	3.5	0.20	0.87	0.06	2.57	0.15
Total	100	2968	-	31.95	-	14.31	-	26.75

The maize cobs themselves however contain a low percentage of nutrients compared to the grain and the rest of the stover. Taking away only the cobs (or not bringing them back to the field) takes 2.3% of the Nitrogen of the whole crop and 6.5% of the Nitrogen left in the stover. Similarly, for Phosphorus and Potassium, taking away just the cobs takes 1.7% of the Phorphorus of the whole crop and 5.2% of the Phorphorus left in the stover and 5.1% of the Potassium of the whole crop and 6.9% of the Potassium left in the stover. It is uncertain and unlikely that removing this small amount of nutrients from the field will have a significant impact on long term soil quality, and a deeper analysis should be conducted.

A similar analysis can be done for the residues of coffee husks and groundnut shells, however in each case, including maize cobs, typically these process residues accumulate through processing and are often not brought back to the field to use as fertilizer.

5.4.5. Water Table

Again, the residues that we use after the harvest would have no impact on the water table or local water supply. Residues taken from the field can decrease water uptake and increase water loss through evaporation. However for this fuel supply, we take process residues not field residues.

6. Implementing Outgrowing Schemes- Woodlots and Agroforestry Systems

The third feasible supply option for this pilot project is to plant and grow trees through outgrowing systems. In this supply option, we would work with our NGO partner, Vi agroforestry, and local farmers in the community to plan and implement agroforestry systems on farmers land and possible woodlots on fallows or marginal land. We plan to use Vi's experitse and successful experience in implementing agroforestry systems in order to design tree systems that fit well with the local agriculture systems and maximize benefits to the community. Vi also has experience with community mobilization, instructing and working with farmers to grow trees.

Appropriate tree species for this outgrowing system

A study as part of the project 'Desigining short rotation coppice based BIOenergy Systems for Rural Communities in East Africa' or (BIOSYRCA, Buchholz and Volk, 2007b) has identified potential tree species for bioenergy projects. The tree species considered include species both native and exotic to Uganda, and were chosen and ranked based on certain desireable properties, including productivity, ability to coppice, survival capacity, and fuelwood quality, among others. Table 26 below gives a summary of the results from the study, ranking each tree species.

These species, listed in Table 26 below, were considered for the site conditions at two specifice sites, the Muzizi Tea Estate, and the Kyangwali Settlement, both in Western Uganda. However these sites have conditions similar to the pilot site at the Magala village in terms of rainfall, altitude, and average temperature.

Of these species considered in the Buchholz study, the three that appear on Vi-Agroforestry's seed list are *Sesbania Sesban, Acacia Mearnsii*, and *Calliandra Calothyrsus.* Although we can plant species outside of this list, we would have to order the seed or seedlings outside of Vi-Agroforestry. In addition, in agreement with partnering on this pilot project, we agree to implement these agroforestry or woodlot systems in accordance with Vi Agroforestry's aims and objectives.

In addition, the study by David Siriri on improved tree fallows in Southwestern Uganda has found the most positive results in terms of firewood yield and net benefits from the two of the species we consider, *Sesbania Sesban* and *Calliandra Calothyrsus.*

Acacia Mearnsii has biodiversity concerns as it is an Alien Invasive Species (AIS) and can outcompete and replace native vegetation. Care and consultanting with Vi will be considered before *Acacia Mearnsii* is planted.

Another species commonly used in woodlots and with great potential for use in SRC systems is *Eucalyptus ssp.* However this is not on Vi's seed list and has some concerns. Eucalyptus has a very fast growth rate and is very productive on a given space of land, however it can have an impact on the local water table if planted in a large scale without proper considerations. Eucalyptus also has a bad reputation of not supporting biodiversity as it produces a toxin that inhibits other plant growth.

Table 26: Summary of tree species considered in the BIOSYRCA project along with considered properties and rankings (Buchholz and Volk, 2007b).

	NATIVE SPECIES			*EXOTIC SPECIES*					
	MARKAHMIA LUTEA	SESBANIA SESBAN	SAPIUM ELLIPTICUM	ACACIA MEARNSII	ALNUS ACUMINATA	CALLIANDRA CALOTHYRSUS	EUCALYPTUS GRANDIS	GLYRICIDIA SEPIUM	LEUCENA LEUCOCEOPHALA
Biomass productivity	M	H	L	H	M	H	H	M	M
Survival capacity	H	H	M	M	M	M	M	M	M
Ecosystem integrity	H	H	H	M	M	M	M	M	M
Propagation	H	H	M	H	H	H	H	H	L
Maintenance	H	H	M	H	M	M	M	M	M
Growth shape	H	H	M	H	H	H	H	H	H
Fuelwood quality	H	H	M	H	H	H	H	M	H
Intercropping potential	M	H	H	M	H	M	L	H	H
Local acceptance	H	H	M	M	L	M	H	L	L
Non timber products	M	H	M	M	L	M	L	H	H
Total H	7	10	2	5	4	4	5	4	4

Total M	3	0	7	5	4	6	3	5	4
Total L	0	0	1	0	2	0	2	1	2

Comments: H=High; M=Medium, L=Low

Eucalyptus is not considered in this pilot project since it is not on Vi's seed list, however it should be considered in future products due to its high quality wood and great productivity. The framework could be used to analyze the tradeoffs of biodiversity and water supply concerns versus those of increased productivity and therefore potentially decreased land use competition.

Although it will be possible and advisable to test other favorable tree species, such as *Markhamia Lutea*, we will focus this section on the three species outlined above, ***Sesbania Sesban, Acacia Mearnsii***, and ***Calliandra Calothyrsus.*** Additional information on these species is provided in the Appendix D.

Amount of Marginal Land Available in the Magala community

In the Magala community, there is a significat amount of land available to plant and grow trees. In an interview with the chairman of the cooperative, he indicated that there was marginal land which was currently available which is owned by the chairman's father. This land covers around 1km^2 or 100 ha and is on a hillsides near the community and telecomm tower.

One of the next steps that needs to be taken is to talk with the chairman's father and to check and see if farmers in the local community can grow on his land. From our impression in talking with the chairman is that he would be willing to help in contribution to this project, however we still need to check this.

Other options for marginal land to use for growing trees in an outgrowing scheme is to check the nearby hillsides, who owns them and if they would be willing to grow trees for this project in an outgrowing system.

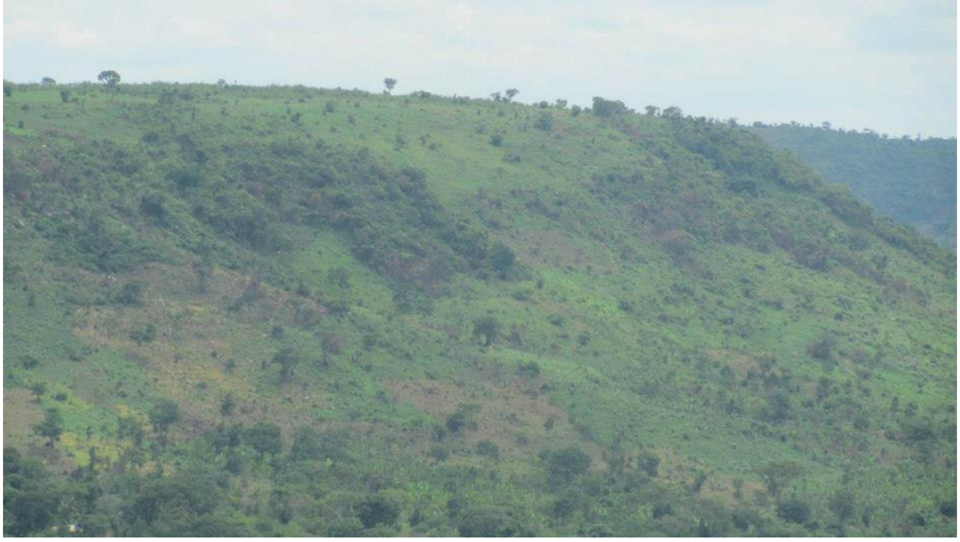


Figure 26: Bare hillside near the Magala village. Litte to no potential for agriculture, however this is suitable for a woodlot.

Other options for land for the outgrowing system includes growing trees on fallow lands (improved tree fallows) or growing trees in hedgerows. From the baseline survey of the Magala community, some of farmers practice fallows and would be willing to grow trees on fallow lands.

5 of the 16 farmer households in the survey indicated that they practice fallows on their land, in times varying from 12 months to 3 years. 3 of these 5 farmers who have indicated they practice fallows also answered that they would be willing to grow trees on their fallow land.

Unfortunately we did not gather information from the survey on the percentage of each land that was left under fallow. (Siriri, *et al.,* 2003) states that from a survey and personal communication with farmers in the Kabale district in Southwestern Uganda, that an average of 22% of land is under fallow for an average time of 14.2 months.

Taking the information from our survey that 5 of 16 households (or 31%) practice fallows, and 3 of 16 farmers (or 19%) are willing to grow trees on these fallows, and also taking the information that of the 11 farmers that answered the survey the average farm size is 8 acres (or 3.24 ha), we can estimate the fallow land potentially available in the local community.

If we take the average farm size of 3.24 ha, the total number of households in the communtiy as 70, 19% willing to grow trees on fallow land, and having 22% of their land fallow, we estimate that there will be potentially around 9.5 hectares of fallow land in the local community available for growing trees.

This is just enough to cover the 8 hectares that are estimated to be needed for a sustainable fuel supply in the long term. This is a conservative estimate and the amount of fallow land available currently to plant trees, however more land can potentially be available with an increase with farmer participation and support, once the benefits of improved tree fallows are explained.

If these trees are planted in hedgerows between crops or in lines as boundaries for fields with a hedgerow width of 1 m, then a total of 80 km of hedgerows will need to be planted. If this length is divided evenly amongst the 250 cooperative members, then on average each member would need to plant 320 meters of 1 m wide hedgerows. This area represents 320 m^2 or .032 hectares.

At an assumed planting density of 10,000 shrubs per hectare or 1 m^2 per tree, each farmer would then plant around 320 trees on average.

With proper discussion and participation from the community, it is likely that this land will be available for planting trees with the community in an outgrowing system.

6.1. Reliability

Potential Challenges for Outgrowing Schemes

There are many challenges and things to consider when beginning an outgrowing scheme and considering the reliability. These include giving the farmers the necessary and high quality inputs as well as information and training to successfully mobilize them to participate in the outgrowing activities. Below are some of the challenges that are especially relevant to this project given from a USAID document on outgrowing schemes (2009).

- Side-selling by farmers, in which farmers that have agreed to sell to the company in the partnership insteads sells to another buyer. The company can face losses as well as difficulties in meeting the commitments they have with their own buyers.
- If farmers not using the inputs provided them for the outgrowing operations, this could result in: 1) lower productivity and quality and 2) difficulty in paying back the credit they received for inputs
- Establishing an outgrowing operation can entail significant start-up costs and require a long-term horizon in order to achieve economies of scale and positive returns for the company
- Outgrowing operations are subject to the same challenges and risks that all agricultural production strategies face (natural disaster, disease, complexity of operations, weather, acquiring needed inputs, etc.)

6.1.1. Suppliers

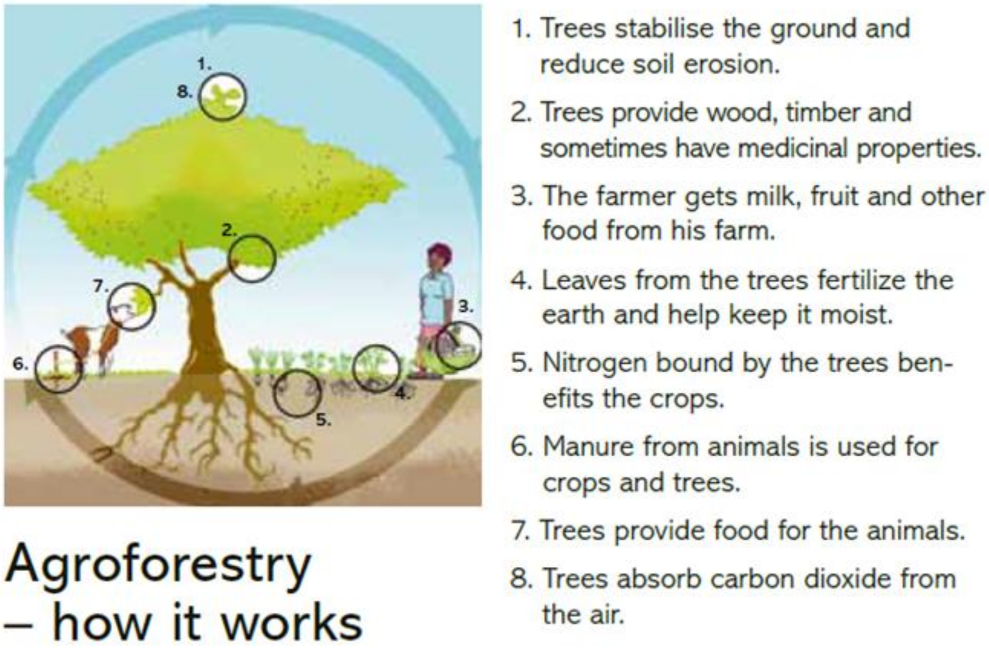
Reliability of Vi Agroforestry

Vi Agroforestry, our development NGO partner, began their projects in 1983 with planting trees to help stop desertification in Kenya. Since then, Vi Agroforestry has expanded through Kenya and also to Uganda, Tanzania, and Rwanda. Since then, close to 100 million trees have been planted throughout to benefit farmers in these areas. In addition, Vi Agroforestry's training, support and education programs have reached over 1 million farmers in East Africa.

Vi has a substantial success record of implementing agroforestry systems, promoting sustainable agriculture, and supporting enterprise development through developing local savings and loan organizations and developing market oriented crop production.

Vi Agroforestry has operated successfully in Uganda since 1992, growing trees and supporting local sustainable agriculture and economic development. Just in 2011 in Uganda, Vi Agroforestry has planted over 1.2 million trees and worked with over 22,000 farmers from 382 farmers groups. Vi has also worked substantially to develop alternative energy sources, working with farmers to construct over 140 biogas plants and selling over 1,000 solar lamps to farmers at a subsidized price (Vi-Skogen, 2012).

Vi agroforestry has much experience in implementing agroforestry systems and growing trees. Some of the systems they have implemented throughout Uganda and East Africa are hedgerow intercropping, trees on fallow land/improved fallows for soil fertility improvement, trees on boundaries of land, trees on soil and water conservation structures, trees on degraded lands, trees on compound/home gardens, woodlots, scattered trees on cropland/ intercropping, fruit orchards, apiculture with trees (bee keeping with trees), and fodder banks (trees for animal feeds) (Komakech, 2012)



Agroforestry
– how it works

1. Trees stabilise the ground and reduce soil erosion.
2. Trees provide wood, timber and sometimes have medicinal properties.
3. The farmer gets milk, fruit and other food from his farm.
4. Leaves from the trees fertilize the earth and help keep it moist.
5. Nitrogen bound by the trees benefits the crops.
6. Manure from animals is used for crops and trees.
7. Trees provide food for the animals.
8. Trees absorb carbon dioxide from the air.

Figure 27: Diagram from Vi-Agroforestry demonstrating the benefits of Agroforestry systems, (Vi-Skogen, 2012).

In partnering with Pamoja in implementing their gasificaiton pilot project, Vi can contribute to their efforts of implementing sustainable energy sources. Vi can help to lend their advice and expertise and implement some of the above agroforestry systems in the local community to supply fuel for the gasifier and benefit local farmers.

Reliability of Farmer Cooperatives

In Uganda alone, there were a total of 10,687 cooperatives registered with the Registrar of Cooperative Development. Of these, 10,641 were primary cooperatives with around 3.9 million members. Agriculture cooperatives represent the majorty of registered cooperatives with over 55% of the total, followed by Savings and Credit Cooperatives (SACCOs), which represent 23% of the total (Kyazze, L.M., 2010).

Cooperative organizations have played a big role in development in Uganda, contributing to local economies, improving livelihood, and benefiting members of local communities, especially women. Agriculture marketing cooperatives allow farmers to come together in a group to market a product so that they assure a more reliable, and often higher, price for their goods. According to a study by the International Food Policy Research Institute, over 90% of farmers reported an increase in income within 5 years after joining a farmer cooperative (Kwapong, *et al.,* 2010).

Cooperatives also come together to buy supplies for farmers in bulk, for example seeds, fertilizers, and pesticides, as well as some farm and processing equipment. This bulk buying of supplies allows the cooperative to sell supplies to the farmer at a cheaper price. The organization and communication within cooperatives also enables increased access of information on more advanced, productive and sustainable farming methods, which can increase their production and decrease their environmental impacts (Fischer, *et al.,*2012). SACCOs allow farmers to contribute to the savings and loan capacity in an organization, taking in money and also supplying beneficial loans to members.

Reliability of the Magala Growers Cooperative

In implementing agroforestry and woodlot systems and growing trees in an outgrowing type system, providing necessary supplies and training to local farmers is crucial. The success of the system though ultimately depends on the ability, willingness and motivation of local farmers to participate in the energy project by growing trees on their land, and contributing to the project by processing and transporting fuel.

According to information from the local baseline survey of 16 farmers, a majority of the farmers were willing to contribute to the project in some way. 4 indicated they would be willing to grow extra trees on their land, 11 mentioned they could help with collecting and transporting residues, and 4 mentioned they would also contribute to transport and processing of the residues or wood.

In addtion from our visits to the Magala community and farmers cooperative, we got a firsthand view of their capabilities to organize and mobilize farmers, their impressive savings and loan capacity, capabilities to organize and run a maize milling business, and their willingness to participate in this project.

Indeed their organization and status as a farmer cooperative has enabled them to start this maize milling business with initial support from Vi-Agroforestry. In addition their status as an cooperative organization facilitates communication and interaction and has allowed for coordination and organized participation in Pamoja's pilot project.

Without this organization it would be much more difficult to coordinate local farmers who generally don't have access to expensive machines which enable a value added business such as mazie miling. This organization of local farmers is necessary as it enables a local business, provides a needed anchor load for Pamoja's energy plant, and enables cooperation for this pilot project.

6.1.2. Supply Dynamics

As covered in the section on the purchasing of firewood, there are issues in the fuelwood supply dynamics in Uganda. Wood supply and natural forests are declining yearly at a rate of around 2%, while demand for fuelwood and wood products are continuously growing (3% per year for firewood, and 6% per year for charcoal). This section however will also consider and focus on the supplies of seeds and tree seedlings, as well as other wood products.

According to the National Forestry Authority of Uganda, the capacity of their tree nursery has expanded from a capacity of 70,000 seedlings annually in 2004 to a current capacity of over 2 million seedlings annually. This capacity reflects the increase in tree planting and growing activities in Uganda (NFA, 2012).

The Sawlog Production Grant Scheme (SPGS) is a collaboration between Uganda, Norway, and the EU to fund the establishment of timber plantations through Uganda. The goal of the SPGS is to support private sector tree plantations in order to deal with this issue of a limted supply of high quality timber products, a growing demand for such products, and to develop a more moden forestry sector.

Since 2004, the SPGS has supported over 300 investors in supporting over 17,000 hectares of timber plantations in Uganda. In supporting about half of the investment costs of a plantation, SPGS has also attracted over $20 million USD of private investment in tree plantations (SPGS, 2012a).

The recent great interest in establishing tree plantations has lead to high demands for tree seeds and seedlings, and local nurseries are stuggling to keep up with this demand. However, SPGS still works to contribute to order high quality seeds and contribute to training and promoting good tree nursery practices.

6.1.3. Demand Dynamics

The demand for high quality seeds and seedlings can be seen from the increase in capacity and supply in both the NFA and SPGS supported nurseries. In addition to this demand for seedlings and increasing number of established tree plantations, there is also a growing demand for wood and wood products.

Poles, Timber and Other Wood Products

In addition, the prices for other high quality wood products such as timber and poles for construction have been constatly rising in recent years. Figure 28 shows the recent increasing prices for both timber and poles.

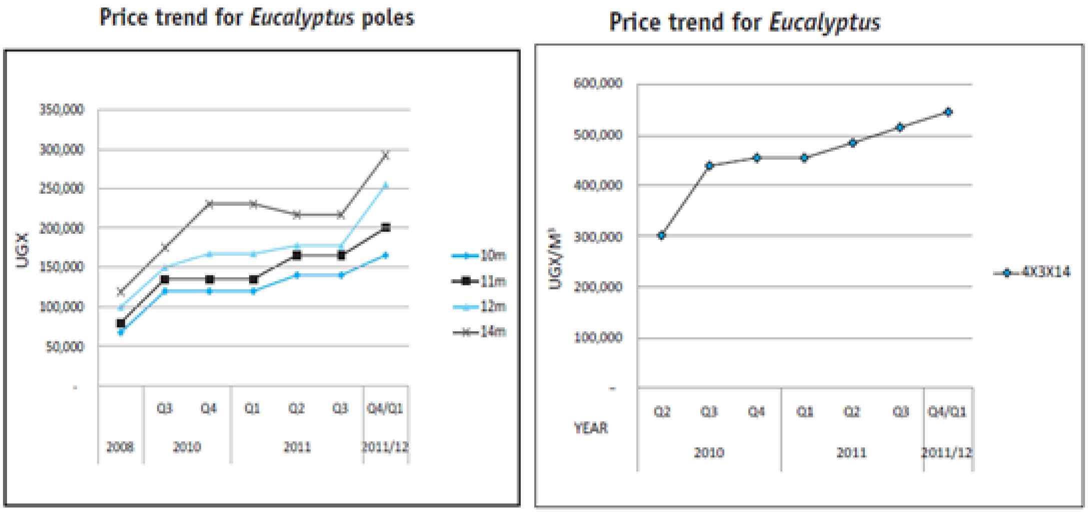


Figure 28: Price trends for Eucalyptus poles (left) and Eucalyptus timber (right) (SPGS, 2012b).

This increase in demand for high value wood products could be an issue for the gasifier fuel supply. If the supply is not properly managed and cut properly, farmers could instead wait a few years longer and have a much higher value product to sell to other buyers instead of contributing wood to this project.

For example, for a Eucalyptus pole with a diameter of 6 inches (15.24 cm) and a length of 10m, has a seasoned (raw, cut) price of 165,000 UGX or $66 USD. A calculation below, in Table 27 in the next page gives a volume and price per oven dried ton for the wood from this Eucalyptus pole.

Given the range discussed earlier in the firewood section of around $21 - $36 USD, this price for Eucalyptus poles is around 20 to 30 times more expensive than common firewood sold on the market.

Eucalyptus timber with dimensions of 4 inches x 3 inches x 14 feet, (10.16 cm x 7.62 cm x 4.26 m), has a price of around 540,000 UGX/ m^3, or \$216 USD/m^3. Given a bulk density for Eucalyptus of 495 kg/m^3, this gives a value of $436 USD/odt, or around 12-20 times the price of normal firewood per odt.

Table 27: Calculation of the Cost of the Wood in a Eucalyptus Pole in terms of $USD/odt.

Eucalyptus pole dimensions and calculations		
Diameter	15,24	cm
Length	10	m
Eucalyptus pole volume	0,182415	M^3
Bulk density for *Eucalyptus*	0,495	odt/m^3
odt of wood in the pole	0,090295	odt
price of a 10m pole	66	USD
price per odt of the wood in the pole	730,94	USD/odt

Therefore there is a possible issue with sideselling, if farmers plant the seeds in a spacing so that they grow taller and can be used for high quality poles or timber. Solutions to this will be to have agreements and to build positive communications and relationships with the farmers so that they know their importance to growing trees to fuel the gasifier. We should also offer the farmers a fair market price for the firewood, similar or higher than the price at which they already sell firewood ($21-$36 USD/odt).

Another possibility to check and make sure farmers are growing trees for this project instead of sideselling is to use agroforestry tree species such as *Acacia mearnsii, Sesbania sesban*, and *Calliandra calothyrsus* that will be beneficial to farmers and good for firewood, but not suitable for high quality timber. Also the trees can be planted in a way with a dense spacing (around 4000-10000 seedlings per hectare) as in SRC systems and coppiced or cut after short time rotations so that the trees do not have a chance to grow wide and tall for these high value products.

6.2. Cost

In this outgrowing scheme, there are many costs that will factor in to the final cost per oven dried ton of firewood. Costs include the initial startup costs for the tree nursery structure, materials and seedlings, as well as costs for some additional materials and seedlings every 6 months for a new batch of seedlings.

In this particular pilot project, some of the costs will be shared by our partner Vi-Agroforestry, for example some of the transport costs, and costs for nursery staff supplied by Vi-AF and field officers in charge of mobilizing and monitoring farmers and tree planting activities. It is planned that Pamoja will help to cover some of the startup costs for the tree nursery.

Through personal and email conversations with Victor Komakech, Environment and Climate Change Coordinator for Vi-Agroforestry in Masaka, Uganda, he shared details of the costs and procedures in setting up a tree nursery, which are outlined in Table 28 below. He has been one of the main contacts for Vi-Agroforestry in this collaboration with Pamoja for implementing this pilot project.

Given these assumptions, around 80,000 seedlings will be planted over the lifetime of this project, and given the conservative assumption of a 50% germination rate, this means that around 160,000 seeds will need to be ordered over the project lifetime.

Table 28: Assumptions of the Tree Nursery and Outgrowing Scheme Considered

Assumptions	Comments
40 odt/yr of biomass required by the gasifier	Pamoja's Calculation
Biomass productivity of 5 odt /ha/year	Conservative Estimate (Buchholz,*et al.,* 2010)
Trees planted at a density of 10,000 seedlings/ha	Typical for plantations of SRC trees
5 year lifetime for the nursery (2 seasons/year)	Estimate from Vi-Agroforestry (Komakech, 2012)
8,000 seedlings produced per season	Capacity given by Vi-AF
2 seed to grow a seedling, or 50% germination rate	Conservative assumption (typical is 65%), (Komakech, 2012)
70% long term survival rate	Komakech, 2012

In addition, given that 8,000 seedlings are produced each season and then soon after planted, and given the density of 10,000 seedlings per hectare, this means that .8 hectares or 8000 m^2 will be planted each season. Over the lifetime of the nursery, 5 years, or 10 seasons, 8 hectares of trees will be planted in the surrounding community. This in a sense means that a sustainable biomass supply for the gasifier will be set up after 5 years.

6.2.1 Initial Costs for Setting up the Nursery

The intial costs for setting up a nursery capable of producing 8,000 tree seedlings per season are 2 million UGX ($800 USD). This includes the nursery structure and materials for growing seedlings, including , polythene tubes, sand, manure, bricks, poles, nails, shade materials, watering cans etc. This, however, does not include the tree seedlings (Komakech, 2012).

The tree seedlings we consider using will be the ones most suitable for coppicing ability as detailed earlier, as well as those most suited for agroforestry systems, especially because of these tree's nitrogen fixing ability. The three species we consider are *Acacia mearnsii, Sesbania sesban,* and *Calliandra calothyrsus.* Table 29 below gives details on the seedlings for each species.

As shown in the table in the next page, if we take 1 kg of seed from each of the three species mentioned, then there will be a total of 183,000 seeds available at a cost of 46,000 UGX or $18.4 USD. Dividing this up over 10 seasons requires 100g of each seed each season, or a total of 18,300 seeds at a cost of $1.84 USD. Adding this total to the $800 USD required for materials for the nursery gives a total cost of around $802 USD for the initial costs and operations in the first season.

Table 29: Prices of Seeds of Selected Agroforestry Species (Vi-Agroforestry, 2012)

	cost/kg (UGX)	seeds/kg	cost/seed (UGX)	seed germination rate
Acacia mearnsii	10000	73000	0,137	63%
Sesbania sesban	6000	90000	0,067	65%
Calliandra calothyrsus	30000	20000	1,5	65%
1kg of each seed	46000	183000		

Other options to Source Tree Seedlings

Another option to source extra seedlings, or species outside of Vi-Agroforestry's seed list is to contact and order seedlings from other local nurseries or from the NFAs tree seed center. Typical cost estimates for buying seedlings from a nursery ready to plant out are around 150-300UGX ($.06-$.12 USD) per seedling. This is a possible backup option to consider with Vi when implementing this outgrowing scheme.

6.2.2 Operation and Maintainance Costs for the Nursery

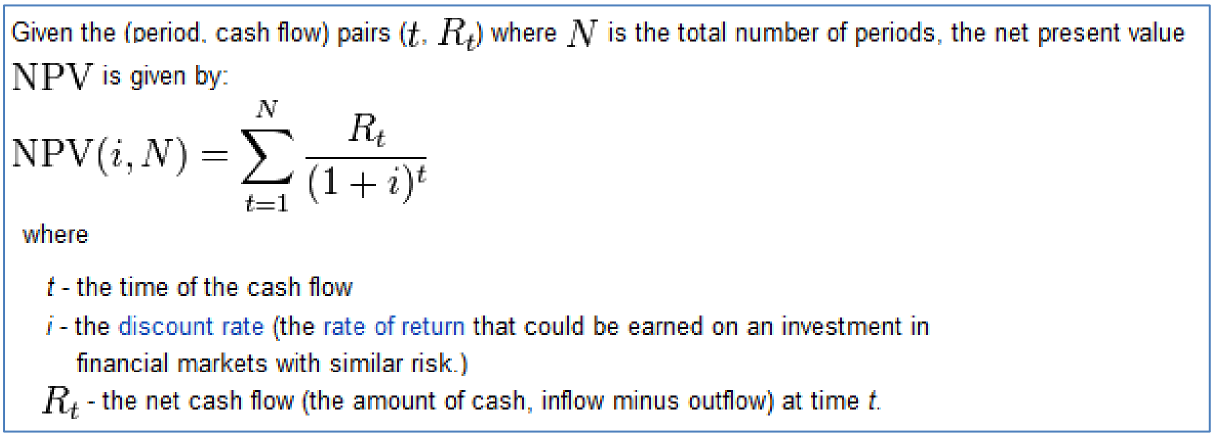
As given by Victor Komakech of Vi-Agroforestry Masaka, the cost for supplies needed for each season are 1.3 million UGX or $520 USD. Adding to this the price of seedlings for each season of $1.84, gives a total cost per season, after the first season, of $522 USD.

6.2.3 Net Present Value (NPV) Analysis for the cost per oven dried ton of wood over the project lifetime.

Woodlots – 20 year project lifetime

A study on REDD and sustainable development in Uganda, which studied the economics of conservation compared to other projects in the Mabira Forest Reserve in central Uganda uses a discount rate of 6.2 percent, given a nominal interest rate of 10 per cent and an average inflation rate of 3.8 per cent per annum (Nabanoga, *et al.,*2010).

In this analysis of the long term costs, in terms of oven dried ton per wood, setting up a nursery and an outgrowing system, we use a Net Present Value (NPV) analysis. First, for each year of the project the net cash flow is determined, cash in-flow minus cash out-flow. This dollar value each future year's cash flow is then discounted at a rate, chosen in this case to be 6.2%, back to the present value. Figure 29 below includes the equation and variables typical in a NPV analysis.



Given the (period, cash flow) pairs (t, R_t) where N is the total number of periods, the net present value NPV is given by:

$$\mathrm{NPV}(i, N) = \sum_{t=1}^{N} \frac{R_t}{(1+i)^t}$$

where

t - the time of the cash flow

i - the discount rate (the rate of return that could be earned on an investment in financial markets with similar risk.)

R_t - the net cash flow (the amount of cash, inflow minus outflow) at time t.

Figure 29: Net Present Value Analysis and typical Equation (taken from wikipedia, 2012)

The NPV analysis for this outgrowing system based on the assumptions above and discounted at 6.8% over 20 years gives a cost of production of $13.37 USD/odt of wood. In other words, at a price of $13.37 USD/odt, the net present value of the outgrowing scheme is zero, which represents the cost of production to Pamoja Cleantech AB. Undiscounted over 20 years, the cost of production is $8.09 USD/odt. The results from the NPV analysis are shown graphically below and also are provided in Appendix E.

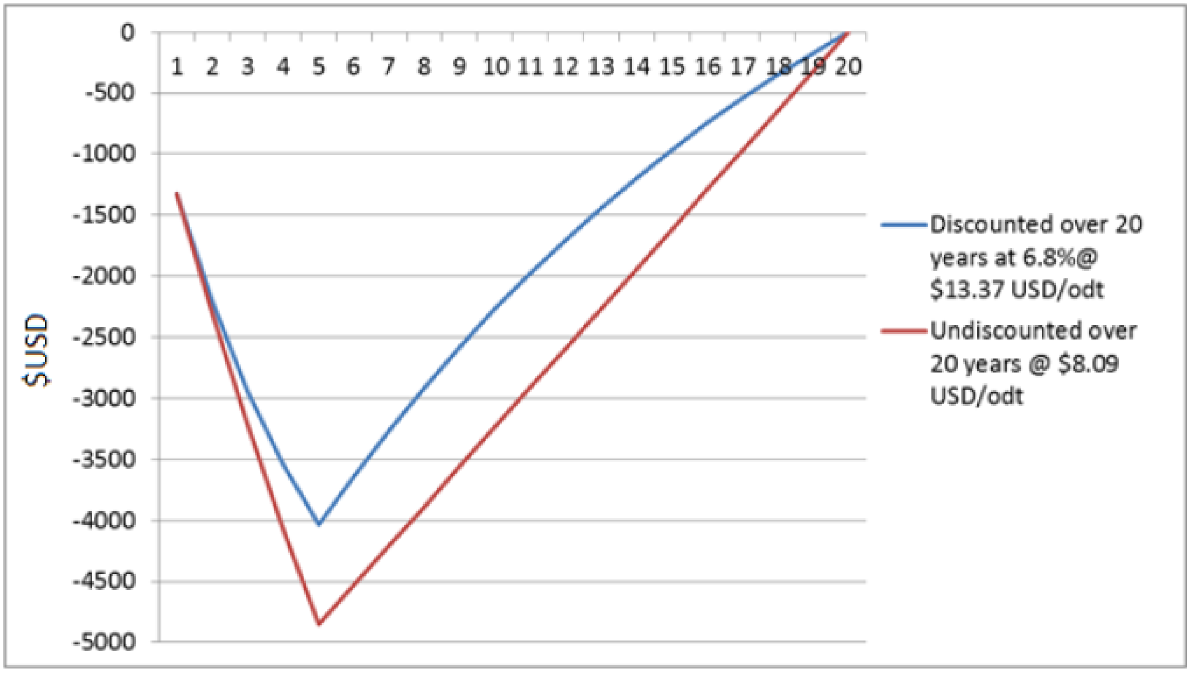


Figure 30: NPV analysis of the cost of production for outgrowing schemes.

This cost of $13.37 USD/odt discounted or $8.09 USD/odt undiscounted represents the costs of setting up and maintaining the nursery in order to produce seedlings, or the cost of production for all the wood in the outgrowing scheme. In this system however, in order to avoid sideselling it is recommended that Pamoja pay a fair market price for firewood to the farmers at the time of delivery.

In considering these production costs, Pamoja can either absorb them into the final cost of electricity, or issue or sell these seedlings on credit equal to this production cost, which the farmers will then pay back upon delivery of firewood. A discussion between Pamoja, Vi, and the Magala village should be conducted and the price and terms negotiated.

Improved tree fallows – 2 year lifetime

In considering the implementation of this scheme on fallow land, using improved tree fallows, the cost per odt of wood produced is higher as the project lifetime is shorter. In using a project and tree lifetime of 2 years on a fallow piece of land, the undiscounted cost of production is $20.25 USD/odt of wood produced.

6.3. Social Impacts

6.3.1. Value Creation

Woodlots on Marginal Land / Hillsides

Once all 8 hectares of trees are established, the community, or the farmers who manage these trees, will have additional value from the wood grown and harvested each year on this land. Assuming a productivitiy of 5 odt/hectare/yr, at least 40 oven dried tons of wood will be produced each year, and at an average price of around $28 USD this represents an additional value for the community of $1120 annually.

Tree Fallows/Hedgerows

In terms of measuring value creation in growing trees we will focus on the most direct monetary benefits to farmers, money from selling firewood from trees, and the expected increase in agriculture production if improved tree fallows are used.

A study on using improved tree fallows in terraces in Southwestern Uganda, gives information on the net benefits of using improved tree fallows over continuous cropping systems and natural fallows. The study takes into account, costs from extra inputs, extra labour, extra revenue from selling firewood, and extra revenue from increased agriculture production due to increased soil fertility.

The returns from crop and wood and the inputs that come after the first year of start of trial were discounted at 10, 20, and 30% for the 2nd, 3rd, and 4th year, respectively. Table 30 presents the results of this study.

Table 30: Financial Analysis (USD) of improved tree fallows on entire terrace bench (Siriri, *et al.*, 2003)

	Land use system					
Discounted parameters	Calliandra	Sesbania	Alnus	Tephrosia	Natural fallow	Continuous cropping
Crop returns (ha−1)	746	729	638	615	475	599
Wood returns (ha−1)	494	721	493	45	0	0
Input costs (ha−1)	222	144	300	106	70	140
Labour costs (ha−1)	389	389	386	365	250	463
Net benefits (ha−1)	629	917	445	189	155	-4

Net benefits (ha−1 per year)	157.25	229.25	111.25	47.25	38.75	-1
Returns to labour (per day)	1.021	1.309	0.841	0.593	0.631	0.387

Some of the best performing species are those we also plan to use in our outgrowing scheme, *Calliandra* and *Sesbania* species. For *Sesbania* and *Calliandra* trees, the net benefits are $229.25 and $157.25 USD/ha/yr respectively over the 4 years of this project. In taking an average of the two values, we get a net benefit of $193.25 USD/ha/yr compared to the net benefit of $38.75 USD/ha/yr in using a natural fallow, or a difference in net benefits of $154.5 USD/ha/yr

Given the assumptions earlier, if a farmer with an average of 3.24 ha of land uses 22% of that (.71 ha) for fallow and plants trees, over 4 years he will gain an additional benefit net benefit of around $110 USD on his land each year.

If we take a value for the monthly income range for farmers of 70,000 UGX/month ($28 USD/month), the annual income estimate is then $336 USD/year. An additional value of $110 USD per year represents around a 33% increase in income, or 4 months of additional income.

Other Non-Monetary Benefits

On the upper terrace, cumulative maize yield after fallow increased significantly from 1.6 tons/ha in the continuous cropping to 5.9 and 6.2 tons/ha in the *Calliandra* and *Sesbania* fallow systems, respectively.

All of the species considered for this outgrowing system are considered to have high quality fodder for animals. This can replace or supplement food requirements for any animals and therefore local farmers can either raise more animals or spend less on animal feed. The research paper on tree fallows in SW Uganda indicates high levels of fodder or green manure produced by these trees.

Calliandra produced 4.9 tons/ha and Sesbania produced 2.2 tons/ha of green manure (Siriri, *et al.,* 2003), which can either decomposed and increase soil organic matter or be used as fodder for animals. As these monetary benefits are indirect and can be hard to estimate or measure, this is listed as a non-monetary benefit and is not quantitatively considered.

6.3.2. Land Use Competition

The trees in the outgrowing scheme will be planted either on marginal hillside land which is unsuitable for agriculture, on fallow land (improved tree fallows) to improve soil quality on fallows, or in hedgerows on farm land in beneficial agroforestry systems. In each of these cases, the aim is to grow trees in an effective manner in order to not compete directly with arable land used for agriculture.

From our surveys with the local community, we see that there is enough marginal land potentially available in nearby hillsides (1 km^2 or 100 ha), and enough farmers willing to grow trees on their fallow land (19% of farmers or 9.5 hectares total) to potentially cover the land demand of the gasifier, 8ha, for a sustainable fuel supply.

Therefore, since there is marginal land and fallow land available to cover our land demands, we assume that we will not have an impact on the current arable land use for agriculture.

6.4. Environmental Impacts

6.4.1. Deforestation and Degradation of Forests

Once the fuel supply is in place through the planting of the trees, there will be a no impact from this project on deforestation in the region since the fuel used by the gasifier will come from these trees.

In fact, if wood is produced above the conservative estimate of 5 odt/ha/year the extra wood can then be used by the community or sold to other markets, possibly reducing in a small sense the pressure on natural forests in the district.

6.4.2. Sustainable Farming Practices

In working together with the farmers and Vi Agroforestry to implement agroforestry systems, we will contribute to the implementation and adaptation of farmers to using more sustainable agriculture practices. In fact one of Vi Agroforestry's main objectives is encouraging sustainable agriculutre practices and more resilliant farm systems through agroforestry and livestock management.

As shown in the study in Southwestern Uganda (Siriri, *et al.,* 2003), tree fallow systems can be implemented without herbicides or inorganic fertilizers. We will implement this system according to the standards of Vi Agroforestry, which discourage the use of herbicides and inorganic fertilizers . The partnership in Vi in implementing these systems will contribute greatly to the adaption of sustainable farming practices in the community.

6.4.3. Biodiversity

Biodiversity in Uganda

As mentioned earlier in section 3.2.3, Uganda is very important in terms of biodiversity, both in numbers and variety of species as a result Uganda's location between and including several ecological zones.

Surveys report the occurrence of at least 18,783 species (NEMA, 2006). In such a relatively small land area (241, 551 km^2), which represents only 0.18% of the world's land and freshwater surface, Uganda contains 4.6% of the dragonflies, 6.8% of the butterflies, 7.5% of the mammals, and 10.2% of the bird species globally recognized. Uganda also has more species of primates than almost anywhere else on Earth of similar land area. The Kibale National Park, which has an area of just 760 km^2, has 12 species of primates. In two Ugandan forests, Bwindi Impenetrable and Kibale National Park, scientists have recorded 173 species of polypore fungi, or 16% of the total species known from North America, Tropical Africa and Europe.

Main Threats to Biodiversity

In Uganda, the four main threats to the conservation of biodiversity are both direct and indirect. The four principle threats are listed below (USAID, 2006).

i) habitat loss/degradation/fragmentation,
ii) unsustainable harvesting and over-exploitation of living and non-living resources,
iii) invasion by introduced species, and
iv) and pollution/contamination.

The threats listed above are a great threat to biodiversity conservation in Uganda, leading to a high rate of biodiversity loss, calculated in 2004 to be between 10-11% per decade. If decreasing forest cover is used as a proxy for biodiversity loss, this shows a significant loss of biodiversity. The extent of tropical high forests, which are rich in biodiversity, have declined from 12% of land area in 1900 to 4% in 2000 (FD, MWLE, 2003).

In terms of conserving biodiversity, the main concern is to protect the remaining areas with natural vegetation, which contain the majority of the species and ecosystems of concern (USAID, 2006). In relation to Pamoja's project, the establishment of a biomass fuel supply can either help conserve or help degrade biodiversity in relation to one of the main threats, unsustainable harvesting or over-exploitation of natural resources. By establishing woodlots and or planting trees in Agroforestry systems, pressure can be reduced in a small extent on the natural forests in the local area. In addition, planting trees can in a small extent contribute to biodiversity conservation, extending habitats for birds and other animals.

6.4.4. Soil Quality

Trees increase the quality of the soil in a variety of ways. Tree roots can hold soil and help prevent erosion of topsoil as well as break through compacted soil and increasewater conductivity. Trees can also provide windbreaks decreasing damage and erosion from wind. Trees also produce large quantities of 'green manure' or organic matter such as leaves and twigs which fall, decompose and can improve soil quality and fertility.

The tree species we consider for this project, *Sesbania, Calliandra,* and *Acacia,* can also improve soil quality by effectively fixing nitrogen from the atmosphere into the soil through the interactions between fungi and the tree roots.

Increasing Mineral Nitrogen Content

In the 2003 study of tree fallows in Southwestern Uganda, levels of mineral nitrogen increased in the upper terrace level from 9.5 mg kg^{-1} in the continuous cropping systems to 17.3 mg kg^{-1} and 13.1 mg kg^{-1} in the *Sesbania* and *Calliandra* fallows, respectively. The table below summarizes the results from the study.

Table 31: Increase in Mineral Nitrogen levels in the soil on different terrace levels and different systems (Siriri, *et al.,* 2003).

	Mineral N (mg/kg)	
System	Upper terrace	Lower terrace
Sesbania sesban	17.23	23.23
Calliandra calothyrsus	13.13	13.26
Tephrosia vogelii	9.87	15.78
Alnus acuminata	9.97	11.30
Acanthus pubescens	10.33	11.98
Natural fallow	9.70	17.61
Continuous cropping	9.50	18.67

According to the study, the higher nitrogen levels in the *Sesbania* and *Calliandra* plots accounted for only 42% of the increase in yields of maize and wheat and the differences between plots. They suggest in the study that the remaining 58% increase can result from differences in soil physical properties, since the trees also improve the physical and hydrological status of the soil (Siriri, et al., 2003).

Improving Soil Quality, Physical Properties and Soil Organic Matter

As mentioned above, this increase in yields due to the improved physical and hydrological status of the soil is supported by backed up by other findings that water infiltration rates, or the rate at which water enters the soil, are doubled under improved fallows (Raussen et al., 1999). The high yield following the Calliandra fallows on the upper terrace can be partly attributed to its ability of Calliandra and its roots to break loose the hard compacted soils. This allows more water infiltration and storage and increases the effective crop root depth (Siriri, *et al.,* 2003).

Increasing Soil Organic Matter Content

Maintaining soil organic matter and soil nutrient status through supplying organic residues, is an essential part of tropical soil health and management. Soil organic matter is the crucial for soil fertility and productivity, and the results from this study show that agroforestry systems have significant potential to increase soil organic carbon compared to control plots.

In the study in SW Uganda, high organic matter, or green manure, production was recorded in plots of Calliandra (4.9 tons/ha) and Sesbania (2.2 tons/ha) plots. Another study finds that agroforestry systems have the potential to sequester between 25 and 70 tonsC/ha in the top 20 cm of soil in tropical regions (Mutuo, *et al*. 2005).

Reducing Soil Erosion

Soil erosion by water is serious global problem. Studies estimate that in Africa, around 5 Mg/ha of productive topsoil is lost to lakes and oceans each year, leading to serious degradation of productive land (Angima, *et al.,* 2003). In 2003, the estimated the annual cost of soil nutrient loss due primarily to erosion was at about $625 million per year (Yaron, *et al.,*2003).

A study on sloping farm lands in Uganda has shown that hedgerow systems using combinations of trees and grasses can be used to reduce erosion, and improve soil fertility and productivity. The hedgerow of *Calliandra calothyrsus and* Napier grass (*Pennisetum purpureum*) was shown to significantly reduce soil loss and runoff, and retain more Nitrogen & Phosphorus (N&P) nutrients (Angima,*et al.,* 2002).

6.4.5. Water Table

There are serious and often underrated implications and considerations for the local water table and balance when planting trees in agroforestry systems or in woodlots. Research suggests a gap between research and policy on land use and water management and the need for improved impact assessments for forests in terms of water use (Calder, 2007).

Research has shown that agroforestry has potential for increasing water use efficiency through utilizing the unproductive sections of the water balance, for example, run-off, soil evaporation and drainage. Research in India and Kenya show that agroforestry systems can double rainfall utilisation compared to continuous cropping systems. In addition this study shows it is important to manage trees through root and shoot pruning in order to reduce competition for water and nutrients with nearby crops (Ong, et al., 2002).

Trees and tree roots can also improve the hydrological status of the soil. In tree fallow systems, studies have found that water infiltration rates, or the rate at which water enters the soil, are doubled. (Raussen *et al*., 1999). Additionally, a study on hilly slopes in Kenya investigated the effects of minimum tillage and vegetative barriers on soil and water conservation. The study showed that a vegetative barrier of *Leucaena trichandra,* a leguminous tree commonly used in agroforestry systems, can effectively catch run-off, effectively utilising water and reducing soil erosion (Guto, et al., 2012).

Although water use efficiency can increase, there are other important things to consider in order not to have a significant negative impact on the water table. Since trees can draw water from deeper down in the soil, large plantations can have a significant impact on the water supply. Proper planning and management are crucial as the impact on long term groundwater storage is related to the plantation area, water table depth, and plantation management. (Keenan, *et al,* 2006).

In the Magala village, Vi Agrforestry has successfully implemented agroforestry systems in the past while considering and not having any significant negative impacts on the local water supply. Based on the relatively small scale of this system and proposed tree planting, and the success of past agroforestry systems, we can confidently assume that this system will have a neutral impact on the water table and also increase effective water utilization. Although a site specific survey of the water table should be conducted through the project to ensure no significant negative impacts.

7. Results

7.1. Weighting and Scoring

In terms of scoring and weighting for these criteria, a simple and even weighting is used. Each criteria (reliability, cost, social impacts, and environmental impacts) will carry the same weight and each sub- criteria will contribute equally to the total score for the criteria. For example, Deforestation and Soil Quality will be weighted the same under the Environmental Impacts critieria which will be weighted the same as, say the Social Impacts criteria. Each fuel supply option will be given a score for each sub-criterion, adding up to the score for the criteria. The scoring is also relatively simple and based on the following scores, given in Table 32.

Table 32: Scoring System for the Criteria and Sub-criteria considered.

Ranking	Score
Very Positive	5
Positive	4
Neutral	3
Negative	2
Very Negative	1

This very simple weighting and scoring system, evenly weights all criteria, which can be later modified or weighted as desired. In fact, it would be interesting to change the weighting on each criteria to see how putting more weight on a certain criteria impacts overall scores. Weighting each social and environmental sustainability criteria on par with reliability and cost reflects the importance and Pamoja's considerations on social and environmental criteria.

The sections below give the scores for each sub-criteria and for each biomass supply option, as well as the total score for each criteria and the overall score out of 20. In addition a small summary and justification of the score given is presented for each supply option and sub-criteria.

7.2. Compiled Scoring of the Fuel Supply Options

The compiled scores for each biomass supply fuel option and sub-criteria are presented below. A score is given based on the system above for each sub-criteria, which then contributes equally to the score for each criteria. The scores for each option are given in the table below.

			Outgrowing Schemes	
Criteria & Indicators	*Purchasing Firewood*	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/ Hedgerows*
Reliability	***3***	***3.67***	***4.33***	***4.33***
Suppliers	5	5	5	5
Supply Dynamics	2	4	5	5
Demand Dynamics	2	2	3	3
Cost	***3***	***2***	***2***	***1***
Social Benefits	***3***	***3.5***	***3.5***	***4***
Value Creation	3	4	4	5
Land Use Competition	3	3	3	3
Environmental Impacts	***2.6***	***2.8***	***4.6***	***4.6***
Deforestation	2	3	5	5
Sustainable Farming Practices	3	3	5	5
Biodiverstiy	2	3	4	4
Soil Quality	3	2	5	5
Water Table	3	3	4	4
Total score out of 20	***11.6***	***11.97***	***14.43***	***13.93***
Total score out of 10	***5.8***	***5.98***	***7.22***	***6.97***

These results are also presented graphically in the radar chart in Figure 31 below.

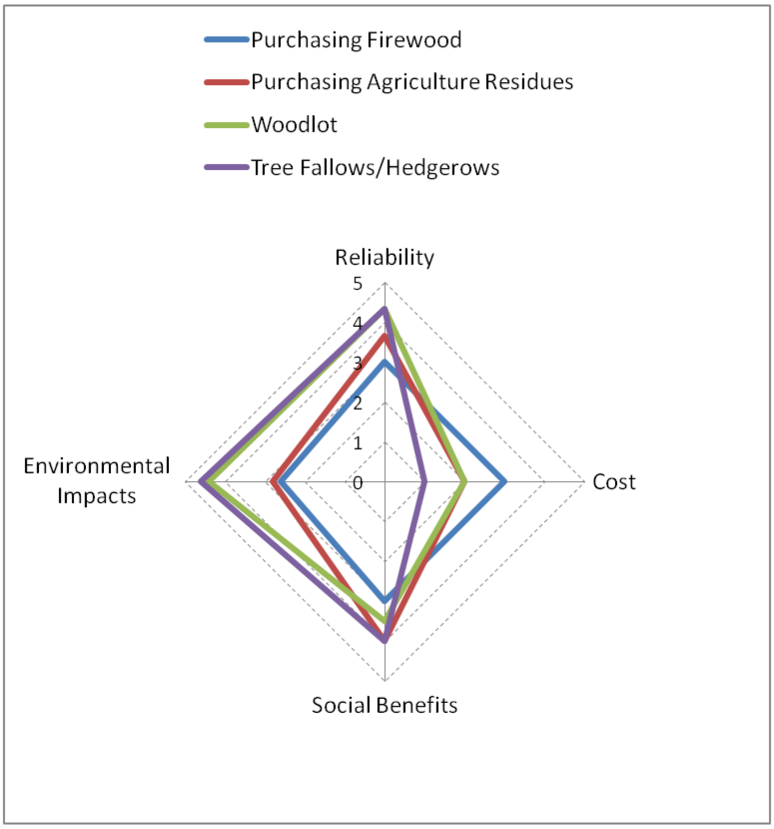


Figure 31: Radar chart displaying how each of the supply options considered scores against the criteria of the sustainability framework.

A full table of the results, as well as a summary of each of the decisions and scores can be found in Appendix F.

8. Discussion

8.1. Discussion of Results

8.1.1. Reliability

From the analysis, all results score high in terms of the reliability of the suppliers. This is due to the fact that the Magala Farmers Cooperative is involved in each supply, and they are considered a very reliabile supplier. In addition, there are other backup suppliers available nearby that we have seen through this field visit, including market suppliers of firewood and argoprocessing businesses which have residues available.

The results from the analysis shows that in terms of reliability of the suppliers, working with well organized farmer cooperatives and the NGO, Vi-Agroforestry, has a great benefit on the reliability of implementing the supply.

Well organized and motivated farmer cooperatives working with Pamoja can be easily mobilized to plant trees in an outgrowing system and to gather residues and wood for the gasifier. They also can help with the processing and storage of the biomass fuel. The successful track record of Vi, their expertise in growing trees, and the fact that they have already visited this community shows that outgrowing agroforestry and woodlot systems can be reliably implemented.

Supply and Demand Dynamics

For purchasing firewood, there is a very clear national picutre of the growing defecit in wood supply, however locally there is a surplus which is currently sold in bulk to suppliers outside the community.

This supply of wood and the price of wood is linked to the national or regional firewood markets in which there is a growing defecit between production and consumption.

The results and analysis show that the other supply options are also somewhat linked to this market, as the demand for all kinds of available biomass is growing. This can result in a market for previously unused agriculture residues, and also sideselling of fuelwood and wood products from trees grown in the community.

Compiled Results for the Reliability Criteria

			Outgrowing Schemes	
Reliability	*Purchasing Firewood*	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/ Hedgerows*
Suppliers	5: Many suppliers present, Local Community and Market	5: Many Suppliers of Residues Available, Reliable Local Community and Other Nearby Suppliers	5: Reliable Suppliers of Seeds/Seedlings Present, Reliable NGO Partner and Farmer Cooperative to Implement the Outgrowing Scheme	
Supply Dynamics	2: Growing National Deficit in Supply	4: Steady National and Local Supply, Subsistence Agriculture, Climate Change Concerns	5: Growing interest in planting trees, Capacity of Nurseries expanding to match.	
Demand Dynamics	2: Growing National Demand for Wood	2: Current Local Demand/Use of Residues, Growing National Demand	3: High demand for wood and wood products, Side-selling is a concern. Although growing our own wood, it’s still connected to the firewood market.	

8.1.2. Cost

In terms of the costs for each supply option, they are all somewhat linked to the market price of fuelwood. Since limited information was available on the selling of agriculture residues in Uganda, the price is estimated based on heating value as linked to the heating value and price of wood.

For outgrowing schemes, farmers would grow biomass and we would then pay a market price for the wood grown. However in the outgrowing option, there are higher initial costs involved in setting up the nursery and growing seedlings. These initial costs will either be paid by Pamoja and absorbed, or given to farmers on credit, and paid back in the future.

In this way, all supply options are linked to the market price of fuelwood.

			Outgrowing Schemes	
	Purchasing Firewood	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/ Hedgerows*
Cost	3:Market Price for Firewood, Rising	2: Limited Info on Selling Residues, Based on Heating Value, similar cost to Wood Market Price.	2: Lower cost, trees stay planted longer in a woodlot, lowering the cost per odt over the project lifetime.	1: Higher Cost per odt if used in tree fallows, trees taken out at the end of the fallow period.

			2/1: Buying the Wood Grown at Current Market Price, extra cost for nursery and seedlings (absorbed by Pamoja or given to farmers on credit).

8.1.3. Social Impacts

In terms of value creation, both the agriculture residues and outgrowing supply options rank high in generating income and value to the local community through the biomass supply. For agriculture residues, this value is generated from the previously unused or un-paid for residues. In the outgrowing scheme, this added value comes from selling the new wood grown and other benefits from growing trees of improved soil quality and yields, among others.

All of these supply options are considered not to have an impact on land use and land use competition. The residues used are process residues from current agriculture practices, and the trees are planned to be planted on the marginal land, hillsides, or fallows, not competing with current land use. There are some minor concerns of leakage effects in the direct buying of firewood from the local communtiy.

			Outgrowing Schemes	
Social Benefits	*Purchasing Firewood*	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/Hedgerows*
Value Creation	3: No New Value Created	5: Value From Using Previously Unused Residues	4: Direct benefits to the cooperative/community	5: More direct benefits to individual farmers
			4/5: Direct income value from selling wood, indirect benefits from increase productivity in following seasons (if tree fallows)	
Land Use Competition	3: No Local Land Use Competition, Small Scale, Leakage Concerns	3: No Local Land Use Competition, Process Residues from Agriculture Currently Practiced	3: No Local Land Use Competition if Trees are Grown on Fallow Land or Woodlots are on Marginal Land/Hillsides	

8.1.4. Environmental Impacts

The first two supply options, directly purchasing firewood and/or purchasing agriculture residues, really do not have any notable impacts on the environmental criteria. There are some concerns of leakage impacts on deforestation and biodiversity, and that using some residues may impact soil quality, however these effects are very minor.

On the other hand, planting trees in an outgrowing system, has a great potential in producing positive environmental impacts as considered in this criteria.

			Outgrowing Schemes	
Environmental Impacts	*Purchasing Firewood*	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/Hedgerows*

Deforestation	2: No local (community) forests affected, Leakage Concerns	3: No Contribution, Small Leakage Concern	5: May Ease Pressure on Natural Forests from Wood Demand
Sustainable Farming Practices	3: No Contribution	3: No Contribution	5: Contributes to Sustainable and Resilient Agriculture Systems
Biodiverstiy	2: No Contribution, Leakage Concerns	3: No Contribution	4: May Ease Pressure on Natural Forests, conserving biodiversity. Also trees can help support biodiversity
Soil Quality	3: No Contribution	2: No Contribution, Potential slight decrease, however unlikely since they are process residues.	5: Multiple Benefits to Soil Quality, increases mineral content (nitrogen), organic matter content, and water conductivity, can reduce erosion. Potential to increase future crop productivity and restore degraded lands.
Water Table	3: No Contribution	3: No Contribution	4: More efficient use of water, higher moisture content, less runoff. Negative effect on water table if trees are planted on a large scale with no management

8.2. Discussion on Pamoja's Sustainable Biomass Framework

The Sustainable Biomass Framework seems to be applicable in assessing the available biomass supply options. However, some considerations should be adressed and revisions and additions made.

One of the issues in this framework is the difficulty in quantitatively measuring the reliability criteria, especially as it relates to the reliability of the suppliers. This criteria seems a bit subjective and hard to measure quantitatively.

Some notable criteria which are absent from Pamoja's Framework but are present in other notable frameworks are the criteria of fair labour standards, including fair pay, good working conditions, and concerns of child labor, and those of legality and complying to local laws and customs. These criteria are absent here, but should be included in a revised framework. These criteria aren't particularly applicable to the supply options considered in this pilot, however they should definitely be considered if Pamoja implements their own vertically integrated tree plantations.

Some environmental criteria not included or assessed include GHG emissions, and other possible pollutants resulting from the biomass supply chain. The issue of the use of inorganic fertilizers, herbicides and pesticides are somewhat covered under the category of sustainable farming practices. However, this section should be expanded in the future to investigate and compare, for example, the added benefits from yields or reliability from applying these inputs versus the negative environmental impacts from their use.

8.3. Other Considerations in Implementing this Biomass Supply

Short term vs. Long Term Supplies

In this project it is important to make a distinction between the short term and long term. While implementing outgrowing schemes and growing trees has advantages in social and environmental benefits, it will take some time, at least 1-2 years in order for the first trees planted to be coppiced and harvested.

In addition according to the rate the planned nursery produces seedlings and our planting density, it will take 4-5 years for the agroforestry or woodlot trees planted to reach their full capacity in fueling the 40 odt requirement from the gasifier. Although implementing outgrowing systems score high and these systems will be implemented in the pilot project by Vi and Pamoja, there is still a need for a fuel supply in the short term, until the full capacity of these trees are reached.

In the short term, agriculture residue are shown to be widely available and score very well as a supply option. This is due to the fact that there are many suppliers available as we have seen from field visits, including the Magala Growers Cooperative and other farmer organizations or agroprocessing businesses in the area.

In addition, the residues chosen are resulting from processing of the crops, or process residues, as opposed to field residues which are typically left on the field conserving organic matter and nutirent content of the soil.

A Mix of Fuel Supply Options

Using a mix of the available supply options increases the quantity of the supply available and the reliability of the supply. In the short term, it has been shown that there are suitable agriculture residues available. However implementing an outgrowing system and growing trees increases reliability in the long term while also providing social and environmental benefits.

The most viable options now seem to use available agriculture residues in the short term while implementing tree growing systems to increase reliability and provide social and environmental benefits.

Purchasing Firewood in the Short Term as a Backup Option

Although it seems unlikely that Pamoja will be unable to source agricultural residues in the short term. However if agriculture residues are somehow unavailable, it may be the case that Pamoja needs to use locally grown firewood as a backup option in the short term before the tree systems are established.

Pamoja is serious about the impacts from this biomass fuel supply and its impacts on the society and environment. One major consideration Pamoja recognizes is the national issue of biomass defecit and deforestation. One option Pamoja can use, if using wood in the short term is necessary, is to account for the wood used and plant trees corresponding to the biomass used. This wood will grow in the future to match the wood consumed presently and can also be discounted in something like a NPV analysis, so that the future quantiy of wood is discounted back to match the present consumption.

9. Conclusion

The fuelwood situation in Uganda is clear; there is still a large problem of a defecit in wood supply available and issues of deforestation along with a growing demand for wood and wood products. These issues occur on a national level and a scale much larger than this project. Even so, Pamoja recognizes this concern and would not like to contribute even further to the problem of wood defecit and deforestation. Indeed, the only way to not contribute to this problem and to help alleviate the growing pressure on wood resources is to plant more trees.

Biomass gasification technology has the potential to improve the quality of life in rural households and significantly contribute to rural sustainable development with only a marginal increase in current biomass consumption. Biomass gasification is a proven renewable bioenergy technology and is economically viable on the scales considered in this project as long as the gasifier runs close to capacity and the biomass supply is sustainably managed.

This thesis aimed to establish a sustainability framework to compare biomass supply options for Pamoja's pilot project and for possible use in future bioenergy and gasification projects in East Africa. The framework was tested against the three viable supply options for this pilot, and scores given for each criteria and each biomass supply option.

Results show that the three investigated supply options, buying firewood from the local market, purchasing agriculture residues, and implementing agroforestry and/or woodlot systems, are comparable economically in terms of the final price per oven dried ton of biomass supplied since they are all somewhat linked to the local market prices for fuelwood. Implementing outgrowing schemes does have a higher initial investment cost in the nursery and preparing seedlings and therefore has a slightly higher cost per odt.

Implementing outgrowing schemes, especially agroforestry systems, have significant advantages over the other two options in terms of potential social and environmental benefits. Although it is challenging to quantitatively measure reliability, we consider implementing agroforestry and woodlot systems to be a slightly more reliable fuel supply option than purchasing firewood or agriculture residues.

For this pilot project, the most viable option now seems to use available agriculture residues in the short term while implementing tree growing systems to increase reliability of the biomass supply and to provide social and environmental benefits. Appropriate agriculture residues (and possibly firewood backup) will be sourced from the Magala community and from nearby communities or trading centers as backups.

The supply will be implemented and managed in collaboration between Pamoja, Vi-Agroforestry, and the Magala community, and its implementation, challenges, and progress should be well studied and documented. In addition, this framework should be adapted, improved upon, and tested for other biomass supply options in gasification and bioenergy projects. Future supply options such as partnerships with other agroprocessing plants or plantations, as well as Pamoja's own vertically integrated biomass supply should be considered and studied as future options.

10. Future Work

10.1. Implementation of the Biomass Supply

There are many other considerations when implementing the biomass supply including biomass supply planning, planning and layout of the tree activities, transport, processing, storage, and drying.

10.1.1. Planning and Implementing the Tree Planting Activities

The planning and implementation will be done after a more through investigation of the site along with Vi- Agroforestry. Given Vi-Agroforestry's expertise and impressive track record in the areas of tree planting activities, the plantation should be planned with close coordination and guidance from Vi.

A site specific layout and plan of activities will be drawn up with Vi at the implementation of the project. This should also include a general meeting with the farmer cooperative, community, and interested farmers.

In addition, during the planning and implementation, an Environmental Impact Assessment (EIA) should be conducted as it relates to the biomass supply and growing trees. In addition, areas of concern for biodiversity and the water table should be noted.

10.1.2. Transport and Processing

In this project, the consideration of transport is minimal since the analysis shows potential for the agriculture residues (and wood as a backup) to be sourced locally and the trees to be grown locally within the Magala village. This reduces costs as well as emissions associated with transport. Backup options from outside this community would likely be source relatively close to this community (within the Sekanyonyi sub-county) and transported by truck as is common in rural Uganda (Figure 15)

Another consideration is the cost of processing the firewood into a size appropriate for use as fuel in the gasifier. A study carried out by the Biomass Energy Resource Center estimates an additional cost between $2 -$10 USD per ton for chipping costs in professional plantations in Vermont. (Sherman, 2007)

This range depends on the size of the chipper and the efficiency of use, and for a small scale project such as Pamoja's pilot, the costs are expected to be around $10/ton or higher. Pamoja will try to buy fuelwood conforming to appropriate dimensions for the gasifier in order to minimize processing costs such as wood chipping.

A suitable option for Pamoja in this pilot project would be a small disk chipper for wood that can run on shaft power or electricity supplied by the gasifier. The APL website gives prices around $1500-$2000 USD for the smallest wood chippers to produce a suitable feedstock (APL, 2012h). Assuming 40 oven dried tons per year and a 10 year lifetime, this would give a price for processing biomass of $3.75 - $5 USD per odt. This range is not discounted for time, and also does not include energy to run the chipper, which can possibly be run off of shaft power or electricity from the gasifier.

Currently, a gasification pilot project through Husk Power System is running in Uganda. For their machine they process the biomass with a shredder costing $1500 USD, which can process 500kg per hour (Katende, 2012). This would give a similar cost per odt over the project lifetime of around $3.75 - $5 USD per odt undiscounted.

10.1.3. Storage and Drying

It is recommended for this project that a storage shed or house be built in order to facilitate in the storage and drying of the biomass for the gasifier. This shed can be combined with the storage shed planned by the Magala community in order to store and dry maize. This shed can also hold processed wood and residues for storage and drying before being used in the gasifier.

Based on the previous gasification projects in Uganda, woody biomass typically dries from a green moisture content of around 50% to an air-dried content of 15% within 6 months. In addition, the storage shed used In the 10 kW gasifier in Mukono had a size of 10m x 4m and a cost of $2500 USD . A picture of the shed is shown in Figure 32.

Figure 32: Gasifier shed with fuelwood storage and processing shed attached (Buchholz, *et al*, 2012).

10.2. Revising and Improving Pamoja's Sustainable Biomass Framework

Pamoja's Sustainable Biomass Framework as presented in this thesis should be revised and improved with considerations from other frameworks. In addition this framework should be tested on other biomass supply options in other bioenergy and gasification projects. Future studies should be conducted and the framework improved.

10.3. Measuring and Quantifying the Indicators Mentioned in this Thesis

In implementing this supply and in future implementations of biomass supplies, it will be important to measure and attempt to quantify the indicators mentioned above. This can be done through more extensive field work, gathering data and analyzing it through tools, for example those described in Beall, E. , *et al*.(2012).

10.4. Future Supply Options and Considerations

Pamoja's Own Intensively Managed Tree Plantations

As shown in the analysis, the price for biomass in these supply options considered is very vulnerable to any fluctuations in the fuelwood market price.

One option considered in the framework that was not assessed in this thesis is buying or leasing land for a biomass supply intensively managed by Pamoja. In this system, Pamoja would buy or lease land and implement a vertically integrated supply, where Pamoja and their employees would be in charge of all aspects of the biomass chain including land preparation, planting and growing, harvesting, transporting and processing. This system would require a larger capital investment, however wood could possibly be grown at a more stable price.

An example from the 250 kW gasifier installed at the Muzizi Tea Estate in Uganda shows that wood can be grown in a SRC woodlot system that is intensively managed at a cost of around $22 per odt including all incurred costs such as land lease, operations and transport (Buchholz, et al. 2012). This price is very competitive with fuelwood market prices and can be more stable compared to the fluctuating wood market. This gasifier system was rated at 250 kW and was on a tea estate and at a larger scale which can reduce the final wood price, so prices are expected to be higher for an operation on a smaller scale. A future analysis on small intensively managed systems is recommended.

An important partner to consider in the implementation of tree plantations is the Sawlog Production Grant Scheme (SPGS). SPGS is a cooperation project between Uganda, the EU and Norway, providing grants and supporting the establishment of professional tree plantations. They have had an amazing track record of success since beginning in 2004, and could be helpful in starting tree plantations to provide fuel to Pamoja's gasifiers in future projects.

Other Options – Business Partnerships and Funds from Carbon Credits and REDD

Other options to consider in the future are partnerships with other large businesses such as tea plantations, agriculture processing plants, or tree plantations and lumber mills. These business partners can provide a symbiotic relationship, as their businesses require heat and electricity which can be provided by a gasifier running on biomass residues from their business, for example agriculture residues or thinnings from tree plantations. A study on the potential of business partnerships or models integrating the biomass supply is also recommended as future work.

Yet another consideration for future projects is applying for additional money or funding for the projects through Clean Development Mechanisms (CDMs), carbon credits, or money through Reducing Emissions from Deforestation and Degradation of Forests (REDD). Implementing this biomass chain and growing trees can also be combined with reforestation efforts and carbon sequestration efforts, and efforts to reduce pressure on natural forests in Uganda.

Applying for these grants and credits often requires lots of time and paperwork and is generally only applicable to larger scale projects. However, if Pamoja scales up to say 60 power plants over the next 10 years as is their strategic plan, the total combined capacity would be 600 kW. With further expansion it might be worth it to put the time and effort into applying for these mechanisms. A study on how extra income from carbon credits or from REDD would effect the economics of this gasification plant is definitely recommended.

11. References

Agroforestree Database, 2002. *A tree species reference and selection guide.* CD Resource, Copyright 2002 World Agroforestry Centre.

AllPowerLabs (APL), 2012a. *Gasification Basics: How it works*. Webpage. Available at: http://gekgasifier.com/gasification-basics/how-it-works/

AllPowerLabs (APL), 2012b. *Gasification Basics: Gasifier Types*. Webpage. Available at: http://gekgasifier.com/gasification-basics/gasifier-types/

AllPowerLabs (APL), 2012c. *Power Pallets: Integrated Gasifier-Genset Skids*. Webpage. Available at: http://gekgasifier.com/gasification-store/gasifier-genset-skids/

AllPowerLabs (APL), 2012d. *Multi-fuel Run Comparison*. Webpage. Available at: http://wiki.gekgasifier.com/w/page/6123786/Multi-fuel%20Run%20Comparison

AllPowerLabs (APL), 2012e. *Biomass Feed Stock Preparation*. Webpage. Available at: http://wiki.gekgasifier.com/w/page/52957241/Biomass%20Feed%20Stock%20Preparation

AllPowerLabs (APL), 2012f. *Gasification Store: Catalog*. Webpage. Available at: http://gekgasifier.com/gasification-store/catalog/

AllPowerLabs (APL), 2012g. *Biomass Requirements of the GEK Gasifier Systems*. Internal Document.

AllPowerLabs (APL), 2012h. *Chippers, chunkers, loppers, splitters, shredders, disintegrators, etc*. Webpage. Available at: http://wiki.gekgasifier.com/w/page/6123688/Chippers%2C%20chunkers%2C%20loppers%2C%20splitters%2C%20shredders%2C%20disintegrators%2C%20etc

Angima, S.D., et al., 2002. *Use of calliandra–Napier grass contour hedges to control erosion in central Kenya.* Agriculture, Ecosystems and Environment 91 (2002) 15–23.

Angima, S.D., *et al.,* 2003. *Soil erosion prediction using RUSLE for central Kenyan highland conditions*. Agriculture, Ecosystems and Environment 97. pp.295–308.

Beall, E. , *et al.,* 2012. *A Compilation of Tools and Methodologies to Assess the Sustainability of Modern Bioenergy.* Bioenergy and Food Security Criteria and Indicators project. Food and Agriculture Organization of the United Nations (FAO).

Bhat, K.M., *et al*., 1990. *Wood Density and Fiber Length of Eucalyptus Grandis Grown in Kerala, India.* Wood and Fiber Science, Vol. 22, N.1. pp. 54-61. Available at: http://swst.metapress.com/content/4584mj05026387h3/

Bingh, L.P., 2004. *Opportunities for utilizing waste biomass for energy in Uganda*. MSc. Trondheim: Norwegian University of Science and Technology, pp. 40-45.

Biopact, 2012. *50MW biomass power plant for Uganda. Available at:* http://news.mongabay.com/bioenergy/2006/10/50mw-biomass-power-plant-for-uganda.html

British Broadcasting Corporation (BBC), 2012. Uganda confirms new oil deposits. Available at: http://www.bbc.co.uk/news/business-19637784

Buchholz , T. et al., 2009. *Multi Criteria Analysis for bioenergy systems assessments*. *Energy Policy* Vol. 37 p. 484-495.

Buchholz , T. et al., 2010. *Potential of distributed wood-based biopower systems serving basic electricity needs in rural Uganda*. Energy for Sustainable Development March 2010, Vol. 14 (1) p. 56-61.

Buchholz,T., *et al*, 2012. *Power from wood gasifiers in Uganda: a 250 and 10 kW case study.* Energy, Volume 165, Issue EN0.

Buchholz, T. & Volk, T., 2007. *Designing short-rotation coppice based BIOenergy SYstems for Rural Communities in east Africa: BIOSYRCA project*. State University of New York, College of Environmental Sciences and Forestry

Buchholz , T. & Volk, T., 2007b. Native species identification and preliminary productivity assessment (Feedstock Assessment). As part of the *BIOSYRCA project*. State University of New York, College of Environmental Sciences and Forestry.

Buchholz, T. & Volk T., 2012. Considerations of Project Scale and Sustainability of Modern Bioenergy Systems in Uganda, Journal of Sustainable Forestry, 31:1-2, 154-173 Available at: http://dx.doi.org/10.1080/10549811.2011.566540

Buragohain, B., Mahanta, P., & Moholkar V., 2010. Biomass gasification for decentralized power generation: The Indian perspective. *Renewable and Sustainable Energy Reviews*, Vol. 14, p. 73–92.

Calder, I.R., 2007. *Forests and water—Ensuring forest benefits outweigh water costs.* Forest Ecology and Management 251 (2007) 110–120.

Corner, A., 2011*. Hidden Heat*: *Communicating climate change in Uganda, Challenges and Opportunities*. Panos East Africa. Available at: http://psych.cf.ac.uk/understandingrisk/docs/hidden_heat.pdf

Council on Sustainable Biomass Production (CSBP), 2012; *Standard for Sustainable Production of Agricultural Biomass*. Version 1.0. Available at: http://www.csbp.org/Portals/0/Documents/CSBP%20Standard%20For%20Sustainable%20Production%20of%20Agricultural%20Biomass%2006122012_1.pdf

de Vries, Bert J.M., van Vuuren, Detlef P., Hoogwijk, Monique M., 2007. Renewable energy sources: their global potential for the first-half of the 21st century at a global level: an integrated approach. Energy Policy 35 (4), 2590e2610.

Devex, 2009. *Pilots Administrator for Biomass Energy Initiative for Africa in Uganda.* World Bank. Project Procurement Posting. Available at: http://www.devex.com/en/projects/pilots-administrator-for-biomass-energy-initiative-for-africa-in-uganda

Fairtrade Labelling Organizations International (FLO), 2011. *Fairtrade Standards for Timber and Forest Enterprises*. Available at: http://www.fairtrade.net/fileadmin/user_upload/content /2009/standards/documents/2011-03-30_EN_Fairtrade_Standard_for_Timber.pdf

Ferguson, H., 2012. *Briquette Businesses in Uganda: The potential for briquette enterprises to address the sustainability of the Ugandan biomass fuel market.* GVEP International. Available at: http://www.gvepinternational.org/sites/default/files/briquette_businesses_in_uganda.pdf

Fischer, E., *et al.,*2012. Linking Smallholders to Markets: Determinants and Impacts of Farmer Collective Action in Kenya. World Development Vol. 40, No. 6, pp. 1255–1268. Available at: www.elsevier.com/locate/worlddev

Forest Department, Ministry of Water Lands and Environment(FD, MWLE), 2003. *National Biomass Study*. National Biomass Study Technical Report, Kampala.

Francescato, 2008. *Wood Fuels Handbook*. Aebiom. Available at: http://nuke.biomasstradecentres.eu/Portals/0/D2.1.1%20-%20WOOD%20FUELS%20HANDBOOK_BTC_EN.pdf

Food and Agriculture Organization of the United Nations (FAO), 2006. *WISDOM – East Africa: Spatial woodfuel production and consumption analysis of selected African countries.* [PDF] Rome: UN FAO. Available at: ftp://ftp.fao.org/docrep/fao/009/j8227e/j8227e00.pdf [Accessed 5 Jan. 2012].

Food and Agriculture Organization of the United Nations (FAO), 2010. *Global Forest Resources Assessment 2010 Country Report: Uganda.* [PDF] Rome: UN FAO. Available at: www.fao.org/docrep/013/al653E/al653e.pdf [Accessed 25 Nov. 2011].

Food and Agriculture Organization of the United Nations (FAO) , 2012. *Criteria and Indicators for sustainable forest management.* Available at: http://www.fao.org/forestry/ci@45047/en/

Forest Stewardship Council (FSC), 1996. FSC International Standard: FSC Principles and Criteria for Forest Stewardship. FSC-STD-01-001 (version 4-0) EN. Available at: http://ic.fsc.org/principles-and-criteria.34.htm

Furtado, J. (2012). Analysis of a biomass-based hybridenergy system for rural electrification: A case study in Uganda. MSc Thesis. KTH. Available at: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-101105

Guto, S.N., et al., 2012. *Minimum tillage and vegetative barrier effects on crop yields in relation to soil water content in the Central Kenya highlands*. Field Crops Research 132 (2012) 129–138.

Hall, C. A. S. (Ed.). (2000). Quantifying sustainable development: The future of tropical economies. San Diego, CA: Academic Press.

Husk Power Systems (HPS), 2012. *Homepage*. Available at: http://huskpowersystems.com/

ICRAF. 2006. International Centre for Research in Agroforestry. World Agroforestry Centre, Southeast Asia web site. Available at: www.worldagroforestrycentre.org/sea

International Energy Agency (IEA), 2011. *World Energy Outlook 2011: The Electricity Access Database*. Available at: http://www.worldenergyoutlook.org/resources/energydevelopment/accesstoelectricity/

Jansen, C. , *et al.*, 2011. *Turning Maize Cobs into a Valuable Feedstock*. Springer Science & Business Media. Available at: http://link.springer.com/article/10.1007/s12155-011-9158-y?null

Kang, B.T. & R.J. Van den Beldt. 1990. *Agroforestry systems for sustained crop production in the tropics, with special reference to West Africa.* Pp 13-33 in Agroforestry land-use systems:

Katende,W., 2012. *Personal Communication.* CEO Pamoja Cleantech Uganda.

Keenan RJ et al, 2006. *Plantations and Water: Plantation Impacts on Stream Flow*. Australian Government Dept. of Agriculture, Fisheries and Forestry. Available at www.acera.unimelb.edu.au/

Komakech, V.,2012. *Personal communication and email with Victor Komakech*, Environment and climate change coordinator at SCC-Vi , Masaka, Uganda.

Kossov, I., 2009. *Uganda's poorest and best paid workers*. Sunday Vision. Available at:

http://www.sundayvision.co.ug/detail.php?mainNewsCategoryId=7&newsCategoryId=777&newsId=689860

Kron, J., 2011. Uganda's Oil Could Be Gift That Becomes a Curse. *New York Times*. 26 Nov. p. A6. Available at: http://www.nytimes.com/2011/11/26/world/africa/uganda-welcomes-oil-but-fears-graft-it-attracts.html

Kwapong, N.A., *et al.,* 2010. *Revival of Agricultural Cooperatives in Uganda.* International Food Policy Research Institute, Uganda Strategy Support Program, Policy Note No. 10. *Available at:* http://www.helsinki.fi/ruralia/ica2011/presentations/Kwapong.pdf

Kyazze, L.M., 2010. *Cooperatives: The sleeping economic and social giants in Uganda*. International Labor Organization. Coop^{AFRICA} Working Paper No.15. Available at: http://www.ilo.org/public/english/employment/ent/coop/africa/download/wpno15cooperativesinuganda.pdf

Lundgren, B.O. and Raintree, J.B. 1992. Sustained Agroforestry. In Nestel, B. (ed.) agricultural Research for Development: Potentials and Challenges in Asia, pp 37-49. ISNAR, The Hague, the Netherlands.

Mayers, J. and Vermeulen, S. 2002. Company-community forestry partnerships: From raw deals to mutual gains? Instruments for sustainable private sector forestry series. International Institute for Environment and Development, London. Available at: http://pubs.iied.org/pdfs/9132IIED.pdf)

McDonald, *et al.,* 2002. *Converging global indicators for sustainable forest management*. Forest Policy and Economics 6 (2004) 63–70.

McKendry, P., 2001. Energy production from biomass (part 3): gasification technologies. *Bioresource Technology*, 83 (2002), pp. 55-63

Ministry of Energy and Mineral Development (MEMD), 2001. *National Biomass Energy Demand Strategy 2001 – 2010: Draft Document.*

Ministry of Energy and Mineral Development (MEMD), 2009. *Energy Balance 2008*. [PDF]

Ministry of Energy and Mineral Development (MEMD), 2010. *Strengthening the Management of the Oil and Gas Sector in Uganda.* Available at: http://www.norway.go.ug/PageFiles/395519/PD%20feb%202010%20incl%20maps.pdf

Ministry of Lands, Housing and Urban Development, 2011. *The Uganda National Land Policy – Final Draft*.

Ministry of Water & Environment, 2010. *Mityana*. Directorate of Water Development.

Mutuo PK, Cadisch G, Albrecht A, Palm CA, Verchot L, 2005. Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. Nutr Cycl Agroecosyst 71:43–54

Muzaale, F., 2012. *600 face eviction from Mityana forest reserves.*In2EastAfrica. Available at: http://in2eastafrica.net/600-face-eviction-from-mityana-forest-reserves/

Nabanoga, G, Namaalwa, J and Ssenyonjo, E (2010). REDD Working Papers: REDD and sustainable development – perspective from Uganda. IIED, London. Available at: http://pubs.iied.org/pdfs/G02774.pdf

National Agriculture Research Organization (NARO), 2001. *Agriculture in Uganda, Volume III: Forestry*.

National Forestry Authority (NFA), 2012. *Facilities and Services at National Tree Seed Centre*. Available at: http://www.nfa.org.ug/content.php?submenu_id=43

Naturland, 2011. *Naturland Standards on Production*. Available at: http://www.naturland.de/fileadmin/MDB/documents/Richtlinien_englisch/Naturland-Standards-on-Production.pdf

NEMA, 2006. *Third National Biodiversity Report*. National Environment Management Authority, Kampala, Uganda.

Okure, M., Ndemere, J.A., Kucel, S.B. & Kjellstrom, B.O., 2006. *Suitability of Agricultural Residues as Feedstock for Fixed Bed Gasifiers*. [white paper] Kampala: Makerere University.

Ong, C.K., et al., 2002. *Tree–crop interactions: manipulation of water use and root function*. Agricultural Water Management 53 (2002) 171–186.

Pamoja Cleantech AB (Pamoja), 2012a. *Internal Documents and Personal Communication*

Pamoja Cleantech AB (Pamoja), 2012b. *The Green Plant*. [website] Available at: http://www.pamojacleantech.com/

Patrick, W. , 2009. *Biomass Charcoal*. Available at: https://wiki.duke.edu/display/engineerswithoutborders/Biomass+Charcoal

Program for the Endorsement of Forest Certification (PEFC), 2010. *Sustainable Forest Management Requirements*. PEFC ST 1003:2010. Available at: http://www.pefc.org/standards/technical-documentation/pefc-international-standards-2010/676-sustainable-forest-management-pefc-st-10032010

Raussen, T., Siriri, D., Ong, C., 1999. Trapping water, producing wood and improving yields through rotational woodlots on degraded parts of bench terraces in Uganda. E. Afr. Agric. For. J. 65, 85–93.

Reijnders, L. (2006). *Conditions for the sustainability of biomass based fuel use*. Energy Policy, 34(7), 863–876.

Roundtable on Sustainable Biofuels (RSB), 2010. *RSB Principles & Criteria for Sustainable Biofuel Production*. RSB reference code: [RSB-STD-01-001 (Version 2.0)] Available at: http://rsb.epfl.ch/files/content/sites/rsb2/files/Biofuels/Version%202/PCs%20V2/11-03-08%20RSB%20PCs%20Version%202.pdf

Rural Electrification Agency (REA), 2007. *Renewable Energy Policy for Uganda*. pp 27. [PDF] Available at: http://www.rea.or.ug/userfiles/RENEWABLE%20ENERGY%20POLIC9-11-07.pdf

Sawlog Production Grant Scheme (SPGS), 2012a. *About SPGS.* Available at: http://www.sawlog.ug/index.php?option=com_content&view=article&id=22&Itemid=105)

Sawlog Production Grant Scheme (SPGS), 2012b, *News of the Commercial Forest Sector in Uganda. Issue 34-35.* Available at: http://www.sawlog.ug/downloads/SPGS%20Newsletters/SPGS%20News%2034-35%20final%20-%20High%20Res.pdf

Sawyer, J. and Mallarino, A., 2007. *Nutrient removal when harvesting corn stover*. Department of Agronomy, Iowa State University. Available at: http://www.ipm.iastate.edu/ipm/icm/2007/8-6/nutrients.html

Schwarze, R., *et al*., 2002. *Understanding and Managing Leakage in Forest-Based Greenhouse Gas Mitigation Projects.* Nature Conservancy. Available at: http://www.ecodecision.com.ec/pdfs/Understanding%20and%20Managing%20Leakage.pdf

SharedSolar, 2011. *SharedSolar Concept Note*. [PDF] Available at: http://sharedsolar.org/wp-content/uploads/2011/02/Concept-Note-SharedSolar-v61.pdf

Sherman, A.R., 2007. *Vermont Wood Fuel Supply Study: An Examination of the Availability and Reliability of Wood Fuel for Biomass Energy in Vermont*. Biomass Energy Resource Center. Available at: http://www.biomasscenter.org/pdfs/VT_Wood_Fuel_Supply_Study.pdf

Sims, R. E. H. (2003, September). *Climate change solutions from biomass, bioenergy and biomaterials.* Agricultural Engineering International: The CIGR Journal of Scientific Research and Development, 5.

Siriri D., *et al.,* 2003. *The agronomic and economic potential of tree fallows on scoured terrace benches in the humid highlands of Southwestern Uganda*. Agriculture Ecosystems and Environment 95 :359–369.

Stassen, H.E., 1995. *Small-Scale Biomass Gasifiers for Heat and Power: A Global Review*. World Bank Technical Paper Number 296, The World Bank, Washington DC, U.S.A. Available at: http://www.woodgas.net/files/World%20bank%20tech%20paper%20296.pdf

TravelsRadiate, 2012. *Sekanyonyi.* Available at: http://www.travelsradiate.com/africa/republic-of-uganda/mubende-district/226363-sekanyonyi.html

Uganda Bureau of Statistics (UBOS), 2010. *Uganda National Household Survey Report 2009/2010*. Section 9.5, Domestic Energy Resources. Available at: http://www.ubos.org/UNHS0910/chapter9_Domestic%20Energy%20Resources.html

Uganda Bureau of Statistics (UBOS), 2011a. *Agriculture.* T3-T6. Available at: http://www.ubos.org/index.php?st=pagerelations2&id=13&p=related%20pages%202:Agric%20%26%20Fisheries

Uganda Bureau of Statistics (UBOS), 2011b. Installed electricity capacity (MW), 2008-2010. Available at: http://www.ubos.org/onlinefiles/uploads/ubos/pdf%20documents/Ener_T2_2011.pdf

Uganda Bureau of Statistics (UBOS), 2012. *Consumer Price Index*. Web Database. Available at: http://www.ubos.org/index.php?st=pagerelations&id=138&p=related%20pages:Consumer%20Price%20Index

Uganda Electricity Transmission Compnay (UETCL), 2012. *Homepage*, Available at: www.uetcl.com/

Uganda Electricity Generation Company LTD. (UEGCL), 2012. *Homepage*, Available at: http://www.uegcl.com/index.html

Uganda Organic Certification Limited (UGOCERT), 2007. *East African Organic Products Standard. EAS 456:2007.* Available at: http://ebookbrowse.com/gdoc.php?id=259848216&url=704e0314f498da0e8aa24ac632e68097

Umeme, 2012, *Umeme Company Profile*, Available at: www.umeme.co.ug/index.php?page=MTUw

UN Energy, 2005. *The Energy Challenge for Achieving the Millennium Development Goals*. New York: United Nations Energy white paper.

(Unique) Tennigkeit, T., Kallweit, K., & Buchholz, T., 2006. *Decentralised rural electricity production from energy forests: Investigating the feasibility of business models for a demonstration project*. [PDF] Unique Forestry Consultants. Available at: http://www.sawlog.ug/downloads/Bioenergy.pdf

United Nations (UN), 1992. *Report of the United Nations Conference on Environment and Development.* Rio de Janeiro, 3-14 June. A/CONF.151/26 (Vol. III) Available at: http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm

United Nations Framework Convention on Climate Change (UNFCCC), 2006. Definition of Renewable Biomass. *CDM Executive Board Report* (EB23), Annex 18, pp. 1. Nairobi, Kenya 6-17 Nov. 2006.

United Nations Framework Convention on Climate Change (UNFCCC), 2012. *Information note: Default values of fNRB for LDCs and SIDs.* Small-Scale Working Group. Thirty-fifth meeting, Report, Annex 20. Available at: http://cdm.unfccc.int/Panels/ssc_wg/meetings/035/ssc_035_an20.pdf

United States Agency for International Development (USAID), 2006. *Uganda Biodiversity and Tropical Forest Assessment.* Available at: http://www.vub.ac.be/klimostoolkit/sites/default/files/documents/uganda_biodiversity_assessment_usaid.pdf

United States Agency for International Development (USAID), 2009. Facilitating the Development of Outgrowing Operations. Available at: http://www.actionforenterprise.org/paper-usaid.pdf'

United States Agency for International Development (USAID), 2012. Uganda Food Security Outlook: July to December 2012. Available at: www.fews.net/docs/Publications/Uganda_OL_2012_07_final.pdf

Vi-Skogen, 2012. *Annual Report 2011 – Vi Skogen.* Available at: http://www.viskogen.se/wp-content/uploads/2012/03/Vi_Agroforestry-2011_web.pdf

Wasige, J., 2009. *Assessment of the Impact of Climate Change and Climate Variability on Crop Production in Uganda.* Global Change SysTem for Analysis, Research and Training (START). Available at: http://start.org/download/gec08/wasige-final.pdf

Waste Management World, 2011. *40 MW Biomass Gasification Facility to Benefit Ugandan Coffee Industry*. Available at: http://www.waste-management-world.com/index/display/article-display/3240177808/articles/waste-management-world/waste-to-energy/2011/02/40_MW_Biomass_Gasification_Facility_to_Benefit_Ugandan_Coffee_Industry.html

The World Bank, 2012a. *Data By Country: Uganda*. [internet database] Available at: http://data.worldbank.org/country/uganda [Accessed 25 Nov. 2012].

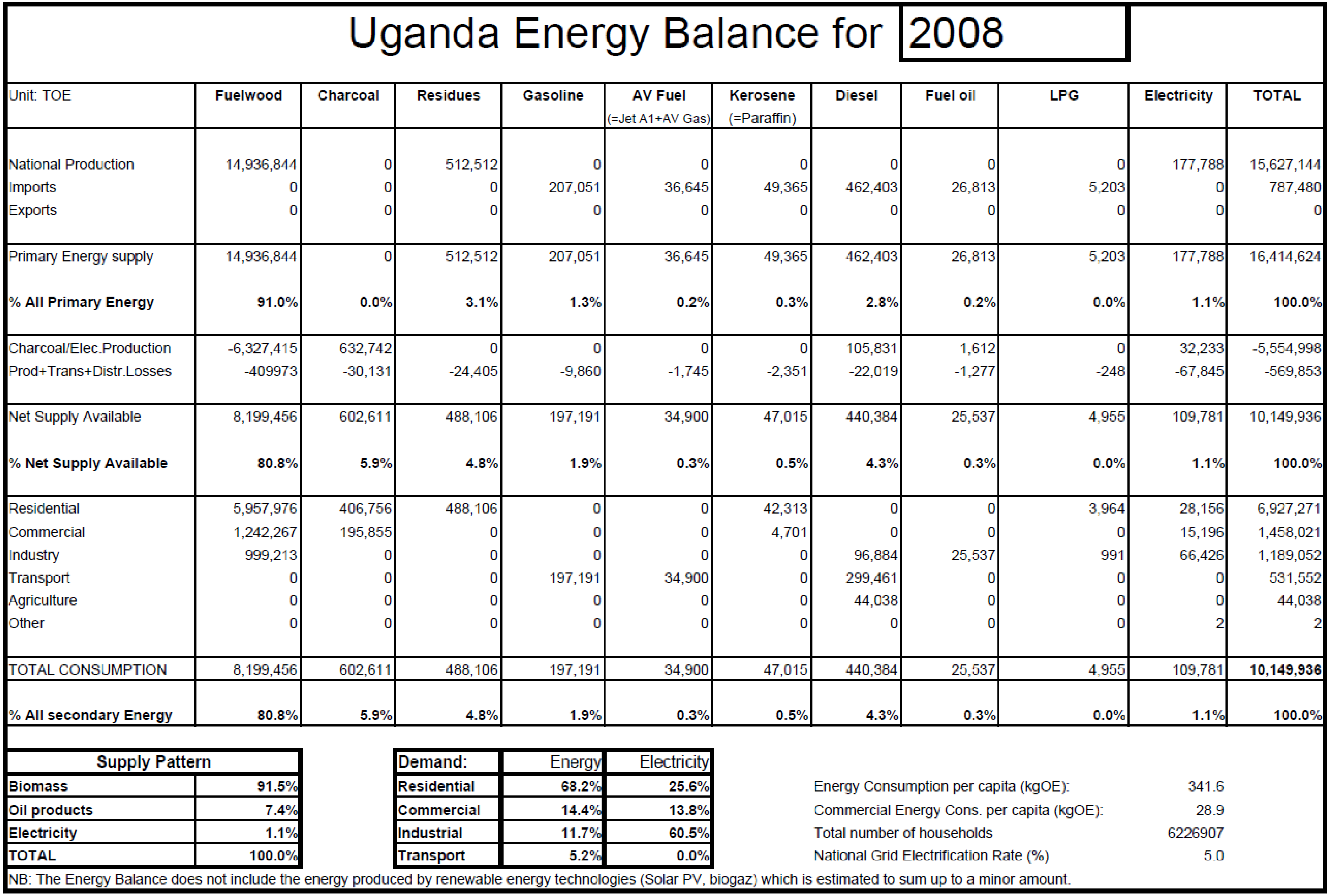
The World Bank, 2012b. *Uganda Overview*. [internet database] Available at: http://www.worldbank.org/en/country/uganda/overview [Accessed 25 Nov. 2012].

World Changing, 2010, *Lighting Africa: Outstanding Products and Distribution Issues.* Available at: http://www.worldchanging.com/archives/011269.html

Yaron G., Y. Moyini et al., 2003. The contribution of environment to economic growth and structural transformation. Report for the ENR working group for the PEAP revision process. MWLE/DFID, Kampala.

Zanchi G, *et al.*, 2012., Climate benefits from alternative energy uses of biomass plantations in Uganda. Biomass and Bioenergy (2012), doi:10.1016/j.biombioe.2012.03.023

Appendix A: Uganda Energy Balance, (MEMD 2008)



Uganda Energy Balance for 2008

Unit: TOE	Fuelwood	Charcoal	Residues	Gasoline	AV Fuel (=Jet A1+AV Gas)	Kerosene (=Paraffin)	Diesel	Fuel oil	LPG	Electricity	TOTAL
National Production	14,936,844	0	512,512	0	0	0	0	0	0	177,788	15,627,144
Imports	0	0	0	207,051	36,645	49,365	462,403	26,813	5,203	0	787,480
Exports	0	0	0	0	0	0	0	0	0	0	0
Primary Energy supply	14,936,844	0	512,512	207,051	36,645	49,365	462,403	26,813	5,203	177,788	16,414,624
% All Primary Energy	**91.0%**	**0.0%**	**3.1%**	**1.3%**	**0.2%**	**0.3%**	**2.8%**	**0.2%**	**0.0%**	**1.1%**	**100.0%**
Charcoal/Elec.Production	-6,327,415	632,742	0	0	0	0	105,831	1,612	0	32,233	-5,554,998
Prod+Trans+Distr.Losses	-409973	-30,131	-24,405	-9,860	-1,745	-2,351	-22,019	-1,277	-248	-67,845	-569,853
Net Supply Available	8,199,456	602,611	488,106	197,191	34,900	47,015	440,384	25,537	4,955	109,781	10,149,936
% Net Supply Available	**80.8%**	**5.9%**	**4.8%**	**1.9%**	**0.3%**	**0.5%**	**4.3%**	**0.3%**	**0.0%**	**1.1%**	**100.0%**
Residential	5,957,976	406,756	488,106	0	0	42,313	0	0	3,964	28,156	6,927,271
Commercial	1,242,267	195,855	0	0	0	4,701	0	0	0	15,196	1,458,021
Industry	999,213	0	0	0	0	0	96,884	25,537	991	66,426	1,189,052
Transport	0	0	0	197,191	34,900	0	299,461	0	0	0	531,552
Agriculture	0	0	0	0	0	0	44,038	0	0	0	44,038
Other	0	0	0	0	0	0	0	0	0	2	2
TOTAL CONSUMPTION	8,199,456	602,611	488,106	197,191	34,900	47,015	440,384	25,537	4,955	109,781	**10,149,936**
% All secondary Energy	**80.8%**	**5.9%**	**4.8%**	**1.9%**	**0.3%**	**0.5%**	**4.3%**	**0.3%**	**0.0%**	**1.1%**	**100.0%**

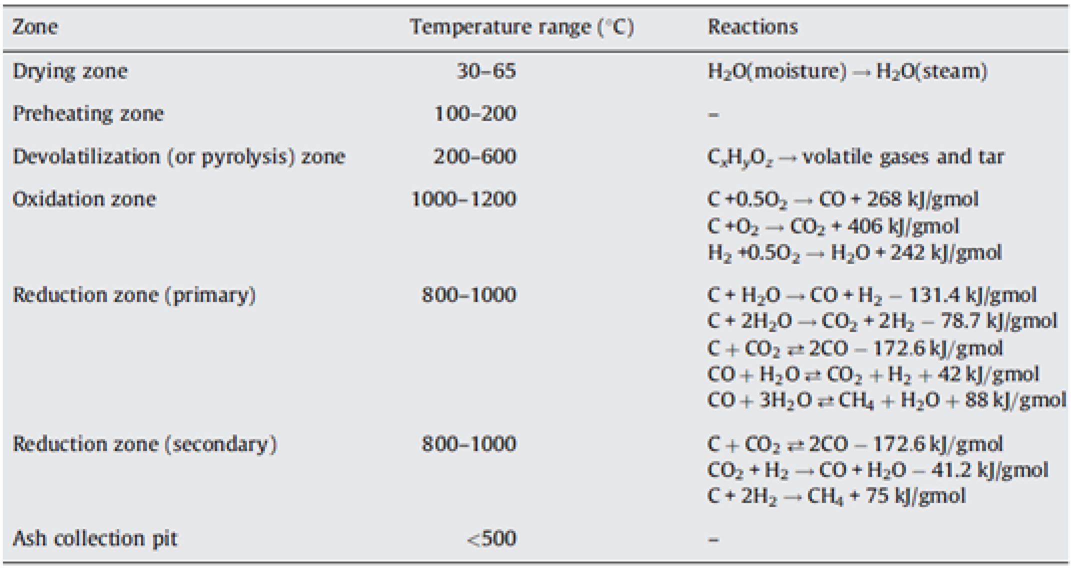
Supply Pattern	
Biomass	**91.5%**
Oil products	**7.4%**
Electricity	**1.1%**
TOTAL	**100.0%**

Demand:	Energy	Electricity
Residential	**68.2%**	**25.6%**
Commercial	**14.4%**	**13.8%**
Industrial	**11.7%**	**60.5%**
Transport	**5.2%**	**0.0%**

Energy Consumption per capita (kgOE):	341.6
Commercial Energy Cons. per capita (kgOE):	28.9
Total number of households	6226907
National Grid Electrification Rate (%)	5.0

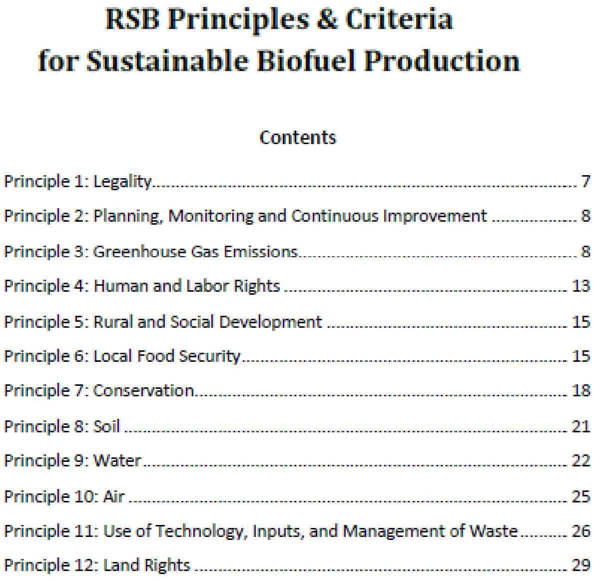
NB: The Energy Balance does not include the energy produced by renewable energy technologies (Solar PV, biogaz) which is estimated to sum up to a minor amount.

Appendix B: Gasification Reactions, Temperature Ranges and the zones in which they occur, (Buragohain, et al., 2010)



Zone	Temperature range (°C)	Reactions
Drying zone	30–65	$H_2O(\text{moisture}) \rightarrow H_2O(\text{steam})$
Preheating zone	100–200	–
Devolatilization (or pyrolysis) zone	200–600	$C_xH_yO_z \rightarrow$ volatile gases and tar
Oxidation zone	1000–1200	$C + 0.5O_2 \rightarrow CO + 268$ kJ/gmol $C + O_2 \rightarrow CO_2 + 406$ kJ/gmol $H_2 + 0.5O_2 \rightarrow H_2O + 242$ kJ/gmol
Reduction zone (primary)	800–1000	$C + H_2O \rightarrow CO + H_2 - 131.4$ kJ/gmol $C + 2H_2O \rightarrow CO_2 + 2H_2 - 78.7$ kJ/gmol $C + CO_2 \rightleftarrows 2CO - 172.6$ kJ/gmol $CO + H_2O \rightleftarrows CO_2 + H_2 + 42$ kJ/gmol $CO + 3H_2O \rightleftarrows CH_4 + H_2O + 88$ kJ/gmol
Reduction zone (secondary)	800–1000	$C + CO_2 \rightleftarrows 2CO - 172.6$ kJ/gmol $CO_2 + H_2 \rightarrow CO + H_2O - 41.2$ kJ/gmol $C + 2H_2 \rightarrow CH_4 + 75$ kJ/gmol
Ash collection pit	<500	–

Appendix C: Principles and Criteria of the Roundtable on Sustainable Biofuels (RSB, 2010) and Forest Stewardship Council (FSC, 1996)



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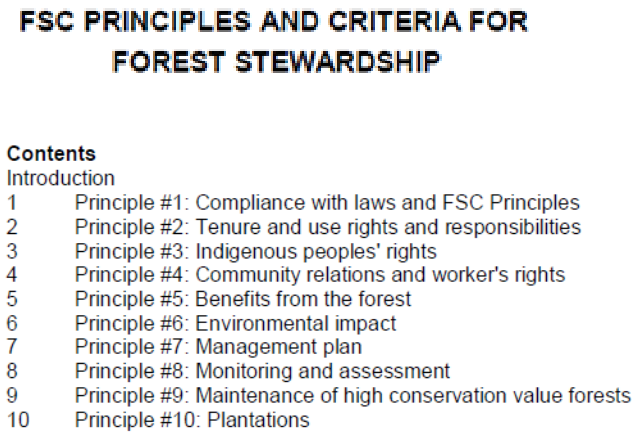

FSC PRINCIPLES AND CRITERIA FOR FOREST STEWARDSHIP

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Appendix D: Additional Information on Appropriate Agroforestry Tree Species

Sesbania Sesban

Figure 33: Flowers of the Sesbania Sesban tree (Agroforestree Database, 2002)

Sesbania sesban is a narrow-crowned, deep-rooting, single or multi stemmed shrub or small tree, 1-7 m tall. *Sesbania sesban* is native to Uganda, grows well in the subtropics and is significant in extending the nitrogen-fixing forage trees into cooler, higher elevation regions of the tropics. The growing conditions, and notable characteristics of *Sesbania sesban*

Altitude: 100-2300 m, Mean annual temperature: (10 min.) 18-23 (45 max.) deg. C, Mean annual rainfall: 500-2000 mm

Soil type: Tolerates seasonal or permanently waterlogged soils as well as saline, acidic and alkaline soils.

One of the major advantages of sesbania over other forage trees and shrubs is its rapid early growth rate, which can be exploited by intercropping it with other slower establishing species for earlier yields. S. sesban thrives under repeated cuttings and coppices readily, with many branches arising from the main stem below cutting height.

Fodder: The tree has a high percentage of foliage nitrogen and is an excellent supplement to protein-poor roughage in ruminant diets. Ruminants readily eat leaves and young branches. These characteristics, together with the generally low crude fibre content and high phosphorous levels, indicate the potential of the species as a high-quality forage source.

Fuel: S. sesban is popular for firewood and charcoal because it produces a high woody biomass in a short time, which, although soft, is relatively smokeless, quick kindling and hot burning. The calorific yield for a 3-year-old tree is approximately 4350 kcal/kg.

Shade or shelter: S. sesban has been used to shade coffee, tea and cocoa. It has also been used as a windbreak for bananas, citrus and coffee.

Soil improver: S. sesban will increase soil nitrogen through symbiotic interaction with bacteria, has the ability to stabilize soil, and in Asia has been used as green manure for rice. Its branches have been used as mulch and leaves as a green manure. S. sesban improves soil fertility in a short-term rotation fallow and is useful in combating striga weed (Striga hermonthica). Some studies indicate that in 1 year a S. sesban fallow can increase maize yields from 2 to 4 t/ha without application of nitrogen fertilizer.

Intercropping: S. sesban is a promising shrub for alley cropping because it is easy to establish, it grows rapidly, coppices readily and provides mulch of high nutrient content (particularly N). In some climates, such as in the highlands of Kenya, it may have a sparse canopy, and weed competition can be a problem. This characteristic makes S. sesban a good intercrop.

Source: Agroforestree Database, 2002

Calliandra Calothyrsus

Figure 34: Flowers of the Calliandra calothyrsus tree (Agroforestree Database, 2002)

Calliandra calothyrsus is a small, thornless, often multistemmed shrub. Under optimum conditions it can attain a height of 12 m and a trunk diameter of 30 cm, but its average height is 5-6 m and diameter 20 cm.

The species occurs in secondary vegetation, often in thickets. It is an aggressive colonizer on disturbed sites such as recent landslides and roadsides. Best development occurs at moderate elevations below 1300 m, and grows best in areas with 2000-4000 mm annual rainfall and a 3-6 month dry period. Growth decreases on compacted soils and trees die after 2 weeks of oxygen depletion due to waterlogging.

Altitude: 250-1800 m, Mean annual temperature: (20) 22-28 deg. C, Mean annual rainfall: 700-4000 mm

Soil type: Grows well on a wide range of soil types but prefers light textured, slightly acidic soils. It can tolerate infertile and compacted or poorly aerated soils but does not tolerate waterlogged and alkaline soils.

C. calothyrsus is fast growing, easy to regenerate and manage. Because seedlings grow quickly, no special plantation management is needed, except for weeding in the 1st year. In alley-cropping systems, C. calothyrsus should be pruned in cycles or up to 4 months to limit shade on associated crops. Highest yields obtained from coppicing when cut at 1 m.

Fodder: Leaves and pods are rich in protein and do not contain any toxic substances. Protein content is 22% (dry matter) and annual fodder yield (dry matter) amounts to about 7-10 t/ha.

Fuel: A good firewood species because it is fast growing, multi-stemmed, easy to regenerate and thornless. One year after planting, annual wood yields have been reported in the order of 15-40 t/ha with annual coppice harvests continuing for 10-20 years. Yields from C. calothyrsus are extremely good in coppice; after being cut at 50 cm from the ground, 3 m high coppices are formed in only 6 months rotation. The rootstock is very vigorous and will sprout readily.

Erosion control: C. calothyrsus can be used to rehabilitate erosion-prone areas and recover land exhausted by agriculture, where it easily dominates undesired weeds such as Eupatrium spp., Saccharum spp., and Imperata cylindrica.

Shade or shelter: C. calothyrsus is often planted as a shade tree around houses. The dense foliage provides protective cover against sun and rain. In forestry it is used as a nurse tree for partially shade-tolerant timber trees such as Agathis species.

Nitrogen fixing: Roots are able to fix atmospheric nitrogen because of the symbiosis with Rhizobium bacteria (to which root nodules bear witness) and the symbiosis with root fungus.

Soil improver: High leaf biomass production and high yields of protein leaf material on less fertile soils make it very suitable as a green manure and it is used in alley-cropping systems. Due to litter and the combination of a deep and well-developed lateral rooting system, the soil and productivity of the land is improved. However, the relatively high level of tannins present in its leaves slows the rate of microbial breakdown of the organic matter.

Boundary or barrier or support: Suitable for hedgerow boundaries.

Intercropping: C. calothyrsus is compatible with crops, with both deep roots and extensive fibrous roots. It has shown promise as an understorey plant in coconut plantations with about 60% light transmission.

Source: Agroforestree Database, 2002

Acacia Mearnsii

Figure 35: Flowers of the Acacia Mearnsii tree (Agroforestree Database, 2002)

Acacia mearnsii is a species exoctic to Uganda, native to Austrailia, small to large, evergreen, single-stemmed or multi-branched tree, 6-25 m high, with a straight trunk, growing to 50 cm in diameter; crown low, spreading, rounded; spines absent; bark brownish-black, hard and fissured; twigs angled, grey, densely hairy, tinged with yellow when young.

A. mearnsii prefers a moderate climate, exhibiting great intolerance to extreme heat or cold. Its lower altitudinal range is decided by the fact that trees cannot stand high summer temperatures, and the upper altitudinal limit is based on the fact that the tree does not tolerate temperatures below 0 deg. C. Adequate soil moisture is a prerequisite for satisfactory growth. Trees cannot withstand drought because of their superficial root system and high rate of transpiration.

Altitude: 300-2 440 m, Mean annual temperature: 9-20 deg. C, Mean annual rainfall: 500-2 050 mm

Soil type: A. mearnsii flourishes in deep, well drained, light textured and moist soils. It thrives in well-aerated, neutral to acid soils, loamy soils, soils derived from shale or slate and is highly intolerant of alkaline and calcareous soils. Soils with lateritic pan close to the surface are most unsuitable.

A. mearnsii regenerates naturally from seed after burning in clear-felled plantations. Seed may lie dormant in the soil for up to 6 years without loss of viability. Profuse seed production and prolonged viability of seed are the features particularly suitable for the silvicultural system of clear felling with natural regeneration.

A. mearnsii has low coppicing power, discouraging people from propagating through coppicing. Protection of trees from fire is necessary, as fire may scorch the bark and reduce its value.

Fodder: The leaves have a high protein content (about 15%). Palatability trials with sheep showed milled leaves to be unpalatable on their own and were acceptable only when mixed with other feedstock. In Hawaii, A. mearnsii has been fed to cattle during drought periods.

Fuel: Originally distributed as a source of tannin, black wattle is now recognized as a valuable fuel wood. Wood is moderately dense with specific gravity about 0.75, splits easily and burns well with a calorific value of 3500-4600 kcal/kg. The charcoal is extensively used in Brazil and Kenya, and in Indonesia the tree is extensively used as a domestic fuel and for curing tobacco.

Timber: The wood is moderately hard to hard, light yellowish to light red, heavy, durable, fairly tough and strong, with a specific gravity of 0.7-0.85; it is moderately easy to work and polishes well. It is used for house poles, mine props, tool handles, cabinet work, joinery, flooring, construction timber and matchwood.

Erosion control: Wattles grow well at high elevations even on slopes with shallow or poor acid soils that are unstable and will not support agricultural crops. They can therefore be very effective in preventing soil erosion. Densely packed plantations have proved effective in preventing further erosion, even on hillsides of up to 50 degrees slope.

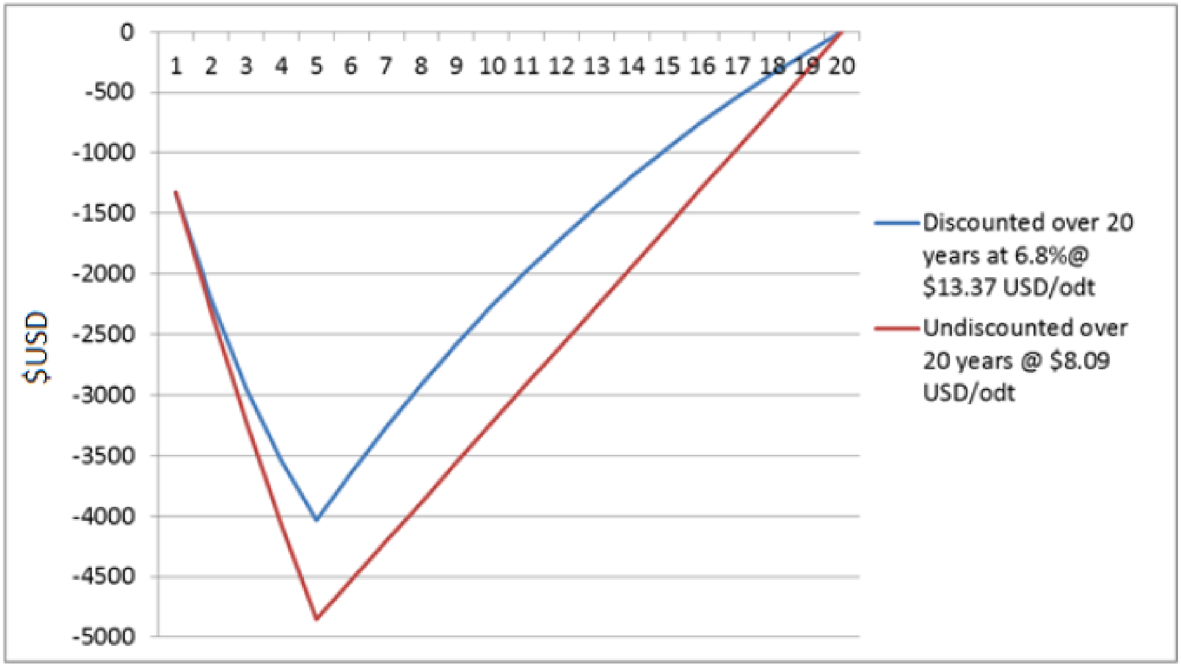
Shade or shelter: The species has been planted as a shelterbelt, a firebelt and as a shade tree in plantations.

Nitrogen fixation: It is an effective nitrogen fixer and has an annual yield of wet leaves of 21-25 t/ha, containing 240-285 kg of nitrogen.

Soil improver: An efficient nitrogen-fixer and good source of green manure, it thus can restore and regenerate soils.

Source: Agroforestree Database, 2002

Appendix E: Net Present Value (NPV) Analysis of the Outgrowing Schemes Option.



(From Section 6.2, Figure 30: NPV analysis of the cost of production for outgrowing schemes.

Table 33: Assumptions used in the NPV analysis

discount rate	6,2%	
Yield	5,00	odt/ha/year
investment	280,00	USD
O&M / year	1040,00	USD
*setting up 1.6 ha/year in the beginning, leading up to 8 years.		
*wood can be cut after 1 year		

Setting up 1.6 ha (16,000 trees) every year for 5 years, wood can be cut after 1 year. Cash outflow (costs) include startup and O&M costs. Cash inflow is calculated by multiplying the hectares producing by productivity (5 odt/ha/year) and by the cost per odt of wood ($13.37 USD/odt, cost of production). The difference gives the cash flow, and taking into the discount rate gives the NPV for each year.

The way this analysis is set up, the price of producing the wood is calculated so that the NPV equals zero after 20 years of producing wood. Using the goal seek function on excel, we get that a value of $13.37 USD per odt of wood, give a NPV of 0. Therefore if the wood is sold at $13.37/odt over the project lifetime, this will cover the cost of production, and this is therefore cost of producing the wood.

Discounted Cost of biomass (per odt, for NPV=0)	**13,37**	**$USD/odt**

Table 34: Cash inflow and outflow for the NPV analysis

year	t=	hectares producing	Cash outflow	Cash inflow	Cash flow (in-out)	**NPV_i**
1	0		1323,68		-1323,68	-1323,68
2	1	1,6	1043,68	106,93	-936,75	-882,06
3	2	3,2	1043,68	213,86	-829,82	-735,76
4	3	4,8	1043,68	320,78	-722,90	-603,53
5	4	6,4	1043,68	427,71	-615,97	-484,24
6	5	8		534,64	534,64	395,77
7	6	8		534,64	534,64	372,66
8	7	8		534,64	534,64	350,91
9	8	8		534,64	534,64	330,42
10	9	8		534,64	534,64	311,13
11	10	8		534,64	534,64	292,97
12	11	8		534,64	534,64	275,86
13	12	8		534,64	534,64	259,76
14	13	8		534,64	534,64	244,59
15	14	8		534,64	534,64	230,31
16	15	8		534,64	534,64	216,87
17	16	8		534,64	534,64	204,21
18	17	8		534,64	534,64	192,28
19	18	8		534,64	534,64	181,06
20	19	8		534,64	534,64	170,49
SUM			5498,4	9088,89	3590,49	**0,00**

Appendix F: Compiled Table of Scoring Results and Discussion.

Compiled Results with Descriptions and Comments on the Score

			Outgrowing Schemes	
Reliability	***Purchasing Firewood***	***Purchasing Agriculture Residues***	***Woodlot***	***Tree Fallows/ Hedgerows***
Suppliers	5: Many suppliers present, Local Community and Market	5: Many Suppliers of Residues Available, Reliable Local Community and Other Nearby Suppliers	5: Reliable Suppliers of Seeds/Seedlings Present, Reliable NGO Partner and Farmer Cooperative to Implement the Outgrowing Scheme	
Supply Dynamics	2: Growing National Deficit in Supply	4: Steady National and Local Supply, Subsistence Agriculture, Climate Change Concerns	5: Growing interest in planting trees, Capacity of Nurseries expanding to match.	
Demand Dynamics	2: Growing National Demand for Wood	2: Current Local Demand/Use of Residues, Growing National Demand	3: High demand for wood and wood products, Side-selling is a concern. Although growing our own wood, it's still connected to the firewood market.	
Cost	***Purchasing Firewood***	***Purchasing Agriculture Residues***	***Woodlot***	***Tree Fallows/ Hedgerows***
Cost($USD/ odt)	3:Market Price for Firewood, Rising	2: Limited Info on Selling Residues, Based on Heating Value, similar cost to Wood Market Price.	2: Lower cost, trees stay planted longer in a woodlot, lowering the cost per odt over the project lifetime.	1: Higher Cost per odt if used in tree fallows, trees taken out at the end of the fallow period.
			2/1: Buying the Wood Grown at Current Market Price, extra cost for nursery and seedlings (absorbed by Pamoja or given to farmers on credit).	
Social Benefits	***Purchasing Firewood***	***Purchasing Agriculture Residues***	***Woodlot***	***Tree Fallows/ Hedgerows***
Value Creation	3: No New Value Created	4: Value From Using Previously Unused Residues	4: Direct benefits to the cooperative/community	5: More direct benefits to individual farmers
			4/5: Direct income value from selling wood, indirect benefits from increase productivity in following seasons (if tree fallows)	
Land Use Competition	3: No Local Land Use Competition, Small Scale, Leakage Concerns	3: No Local Land Use Competition, Process Residues from Agriculture Currently Practiced	3: No Local Land Use Competition if Trees are Grown on Fallow Land or Woodlots are on Marginal Land/Hillsides	

Environmental Impacts	***Purchasing Firewood***	***Purchasing Agriculture Residues***	***Woodlot***	***Tree Fallows/ Hedgerows***
Deforestation	2: No local (community) forests affected, Leakage Concerns	3: No Contribution, Small Leakage Concern	5: May Ease Pressure on Natural Forests from Wood Demand	
Sustainable Farming Practices	3: No Contribution	3: No Contribution	5: Contributes to Sustainable and Resilliant Agriculture Systems	
Biodiverstiy	2: No Contribution, Leakage Concerns	3: No Contribution	4: May Ease Pressure on Natural Forests, conserving biodiversity. Also trees can help support biodiversity	
Soil Quality	3: No Contribution	2: No Contribution, Potential slight decrease, however unlikely since they are process residues.	5: Multiple Benefits to Soil Quality, increases mineral content (nitrogen), organic matter content, and water conductivity, can reduce erosion. Potential to increase future crop productivity and restore degraded lands.	
Water Table	3: No Contribution	3: No Contribution	4: More efficient use of water, higher moisture content, less runoff. Negative effect on water table if trees are planted on a large scale with no management	

Compiled Scores

			Outgrowing Schemes	
Criteria & Indicators	*Purchasing Firewood*	*Purchasing Agriculture Residues*	*Woodlot*	*Tree Fallows/ Hedgerows*
Reliability	***3***	***3.67***	***4.33***	***4.33***
Suppliers	5	5	5	5
Supply Dynamics	2	4	5	5
Demand Dynamics	2	2	3	3
Cost	***3***	***2***	***2***	***1***
Social Benefits	***3***	***3.5***	***3.5***	***4***
Value Creation	3	4	4	5
Land Use Competition	3	3	3	3
Environmental Impacts	***2.6***	***2.8***	***4.6***	***4.6***
Deforestation	2	3	5	5
Sustainable Farming Practices	3	3	5	5
Biodiverstiy	2	3	4	4

Soil Quality	3	2	5	5
Water Table	3	3	4	4
Total score out of 20	***11.6***	***11.97***	***14.43***	***13.93***
Total score out of 10	***5.8***	***5.98***	***7.22***	***6.97***