Institute of Water and Energy Sciences (Including Climate Change)

TECHNO-ECONOMIC FEASIBILITY OF A GASIFICATION PLANT FOR RURAL ELECTRIFICATION, UNDER A BAMBOO BASED SUSTAINABLE ECONOMIC MODEL: Case of Bududa District in Eastern Uganda

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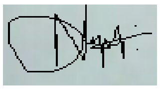
DECLARATION

I, **Irene Nantongo,** hereby declare that this thesis represents my personal work, realised to the best of my knowledge. I also declare that all information, material and results from other works presented here have been fully cited and referenced in accordance with the academic rules and ethics.

Signed: 5th September 2017



Irene NANTONGO

CERTIFICATION

This thesis has been submitted with my approval as the supervisor

Signed 5th September 2017

Dr. Fouzi Tabet

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DEDICATION

This work is dedicated to my father, Mr. Ssentongo Vincent Ferrer, a unique man, a multi-disciplined natural engineer from whom I obtain most of my inspiration and encouragement.

ABSTRACT

Majority of Ugandans cannot be able to afford electricity even if it was accessible due to a high degree of poverty. Within its means and current available resources, Uganda is supposed to increase energy access, urgently adjust to the available ways of mitigation of climate change, as well as provide quick solutions to the people to improve their livelihoods and income. It would therefore be necessary to explore environmentally clean energy sources while simultaneously creating sources of income for the population in order for the people to afford and access the clean energy. The Bamboo plant is now famous for being one of the top solutions to quick economic growth and mitigation of climate change due to its numerous unique characteristics. Uganda has embraced this plant with several small-scale mushrooming bamboo based businesses. Unfortunately, much as several developmental projects on energy are coming up and thriving in other countries using bamboo, Uganda has not yet explored this option.

The aim of this study is to assess the techno-economic feasibility of a bamboo Biomass Gasifier Power Plant (BGPP) for rural electrification along with an innovative sustainable rural development concept. The technical feasibility is analysed in comparison to previous existing installations worldwide. The economic costs are estimated using particular assessment templates and equations from literature, along with Microsoft Excel.

The study shows that the sustainable bamboo based concept for rural economic growth is applicable to Bududa district and has potential of meeting at least 14 of the 17 Sustainable Development Goals (SDG’s) assuring increased income and some guarantee that the local population will be able to afford the generated electricity by the BGPP. It indicates a possibility of earnings up to $12,000 per hectare per year.

Bududa district was estimated to have a load of 1.14MW requiring a BGPP with power output capacity of 4.1426MW. 0.88% of the total land area of Bududa district is required specifically for bamboo feedstock plantation to run the BGPP year-round with a potential of 60,077 tons of carbon storage each year and 1,225.57 tons of carbon absorbed by the bamboo plantation each year. The BGPP is found to be economically feasible with small profit margins. The LCOE is 0.18486 USD/kWh, the Net Present Value is USD 367,908.4, the Internal Rate of return is 10.5195% greater than the discount rate by 0.5195%, and a Payback period is 8.22 years.

Key words: Bioenergy, Sustainable development, Climate change, Innovation.

RESUME
La majorité des Ougandais ne peuvent pas se permettre l'électricité même si elle était accessible en raison d'un degré élevé de pauvreté. Avec ses moyens et des ressources actuelles disponibles, l'Ouganda est censé s'adapter de manière urgente aux moyens d'atténuation des changements climatiques disponibles, ainsi que fournir des solutions rapides aux personnes pour améliorer leurs moyens de subsistance et leurs revenus. Il faudrait donc explorer des sources d'énergie respectueuses de l'environnement tout en créant simultanément des sources de revenus pour la population afin d'avoir accès à l'énergie propre et à y accéder. La plante de bambou est devenue aujourd'hui très célèbre pour être l'une des meilleures solutions à la croissance économique rapide et à l'atténuation des changements climatiques en raison de ses nombreuses caractéristiques uniques. L'Ouganda a embrassé cette plante avec plusieurs petites entreprises à base de bambou. Malheureusement, tant que plusieurs projets de développement sur l'énergie se développent et prospèrent dans d'autres pays à l'aide de bambous, l'Ouganda n'a pas encore exploré cette option.

L'objectif de cette étude est d'évaluer la faisabilité technico-économique d'une centrale électrique de gazéification à biomasse de bambou (BGPP) pour l'électrification rurale dans un concept innovant de développement rural durable. La faisabilité technique est analysée par rapport aux anciennes installations existantes dans le monde entier. Les coûts économiques sont estimés à l'aide de modèles d'évaluation particuliers et d'équations avec Microsoft Excel.

L'étude montre que le concept durable de bambou pour la croissance économique en zone rurale est applicable au district de Bududa et a le potentiel de répondre au moins 14 des 17 objectifs de développement durable (SDG) assurant un revenu accru et certains garantissent que la population locale pourra se permettre l'électricité générée par le BGPP. Cela indique une possibilité de gains jusqu'à 12000 $ par hectare par an.

On estimait que le district de Bududa avait une charge de 1,14MW nécessitant un BGPP avec une puissance de sortie de 4,1426MW. 0,88% de la superficie totale du district de Bududa est nécessaire spécifiquement pour l'exécution du BGPP toute l'année, avec un potentiel de 60077 tonnes de stockage de carbone chaque année et 1225,57 tonnes de carbone absorbé par la plantation de bambou chaque année.

Le BGPP est économiquement réalisable avec de petites marges bénéficiaires avec l'analyse de l'investissement. Le LCOE est de 0,18486 USD / kWh, la valeur actuelle nette est de USD

367908,4 le taux de rendement interne est de 10,5195% supérieur au taux d'actualisation de 0,5195%, et une période de récupération est de 8,22 ans.

Mots clés: Bioénergie, Développement durable, Changement climatique, Innovation.

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List of Abbreviations

BFB	Bubbling Fluidised Bed
BGPP	Biomass Gasifier Power Plant
BPM	Benefit Point Method
capex	capital expenditures
CFB	Circulating Fluidised Bed
CH_4	Methane
CHP	Combined Heat and Power
CO	Carbon monoxide
CO_2	Carbon dioxide
DFC	Direct Fixed Costs
DG set	Diesel Generator set
ERA	Electricity Regulatory Authority
FiT	Feed in Tariff
FOM	Fixed Operation and Maintenance
FOM	Fixed Operation and Maintenance costs
GW	Gigawatt
GWh	Gigawatt hour
H_2	Hydrogen
H_2O	Water
ha	hectare/s
HHV	High Heating Value
HRSG	Heat Recovery Steam Generator
ICE	Internal Combustion Engine
IGCC	Integrated Gasification Combined Cycle
IRR	Internal Rate of Return
LCE	Levelised Cost of Electricity
LHV	Lower Heating Value
MEMD	Ministry of Energy and Mineral Development
MJ	Mega Joules
MSW	Municipal Solid Waste
MW	Megawatt
MW_e	Megawatt electrical
MW_{th}	Megawatt thermal
N_2	Nitrogen
NO_x	oxides of Nitrogen
NPV	Net Present Value
O & M	Operation and Maintenance
odt	oven dry tons
opex	operating expenditures
RE	Renewable Energy
REA	Rural Electrification Authority
SPPA	Standard Power Purchase Agreement

SREP	Scaling up Renewable Energy Program
t	ton/s
UBOS	Uganda Bureau of Statistics
UECCC	Uganda Energy Credit Capitalisation Company
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UIA	Uganda Investment Authority
VOM	Variable Operation and Maintenance
VOM	Variable Operation and Maintenance costs

Conversion factors

1 month	=30 days =720 hours
1year	= 365days
1 t	= 1000Kg
1 ha	= 0.01 Km^2

CHAPTER ONE: INTRODUCTION

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1.0. INTRODUCTION

This chapter gives a brief overview of the background of this study, the objectives, the scope and the justification as to why this study is very necessary at this point in time.

1.1. RESEARCH BACKGROUND AND JUSTIFICATION

The struggle to "light up" Africa will continue at a very slow rate because electricity access could be least of priorities for a population still struggling to meet other basic needs such as food, clothing, shelter and health. It can only be possible to quicken the target of energy access if new energy projects are introduced simultaneously with income generating and economic growth projects.

Sub-Saharan Africa is one of the regions with least energy access in the world. At the same time, the largest group of people living in extreme poverty with no access to life's very basic needs such as food, clothing and shelter are found in this region. As a result, effects of climate change hit this population harder than elsewhere in the world making the people even poorer. A population with such characteristics can never be able to afford clean and modern energy making renewable energy systems economically and technically un-feasible. Yet, it is more than necessary to build clean energy systems for such a population in order to create development and also create opportunities for this population to actively, positively participate in adaptation and mitigation of climate change. In the long run, it is expected that the population would sufficiently afford the energy generated by the gasification plant and also be able to live better livelihoods with no negative effect on the environment.

Module 10 of the document "Sustainable energy regulation and policy making for Africa" concludes that rural energy development must be integrated with other aspects of rural development [103]. Uganda is suffering from "the vicious cycle of energy poverty" which starts by lack of energy to run machines resulting into low productivity, poor quality and range of output, low surplus, little cash and therefore lack of money to buy improved energy supplies and energy conversion equipment and finally the cycle ends back in lack of energy. This cycle of energy poverty can be broken by combining provision of improved energy services with end uses that generate cash incomes [103].

Biomass conversion to fuel gas, which is termed as gasification, is the key technology for biomass based power generation [115]. Gasification technology has been found as one of the most viable options for mass rural electrification for areas far away from the grid system by many studies [139]. One study by Mahapatra et al (2011) concluded that for far away villages, biomass gasification base systems are economically more competitive than photovoltaic base systems or grid extensions [106]. The International Finance Corporation (IFC) and HPS are promoting these systems in Kenya and Nigeria. In Benin, GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH) is promoting biomass gasification for Combined Heat and Power (CHP) generation in decentralized settings as an economic alternative to grid extension in remote areas of the country [139]. Biomass gasification systems have also already been proven to be very suitable and economically viable for rural electrification in Uganda [80]. Their success and long-term sustainability is dependant mainly on availability, reliability and sustainability of the biomass resource used [80].

The bamboo plant has gained international fame especially in the era of climate change due to its possession of numerous economic, environmental and biomass resource potential characteristics and advantages compared to any other living plants. Bamboo is famous for being easy to propagate with vigorous regeneration, fast growth, high productivity and quick maturity [107]. The plant has gotten a reputation of transforming rural populations economically, environmentally but especially for its possession of unique energy characteristics for application to renewable energy systems.

Massive projects on plantation of bamboo are however location sensitive because of its unique growth characteristics and environmental factors discussed in this thesis. It is necessary therefore to recommend bamboo based projects for specific regions with suitable physical, social, environmental and economic characteristics.

This study intends to contribute towards rural electrification while subsequently suggesting a sustainable economic development concept that will ensure affordability of the generated electricity.

1.2 PROBLEM STATEMENT

Uganda is one of the least developed countries of the world based on its low Gross National Income (GNI), weak human assets and a high degree of economic vulnerability [93]. About 19% of the population live below USD 1.90 [71] having a very high rate of unemployment especially among the youth [73]. The government of Uganda is financing external and internal debt burdens and can hardly meet the national budget on its own. Its total public debt is expected to peak in 2020/21 at about 50% of GDP and is under constant monitoring by IMF and World Bank [93]. Continuing to give free and over subsidized services to the people such as energy and education has proven inefficient due to limited financial budgets and also partly due to high levels of corruption in the public sector. The several Non-Government Organisations (NGO's) and donor bodies supporting Uganda's poor are also trying to do a fair job but which is not sustainable especially in the long term. Extreme poverty among majority Ugandans and the fact that little financial support is therefore expected from the government makes it almost impossible to create feasible economic developmental projects for especially the rural areas that are most vulnerable and most vast.

Besides having one of the highest annual population growth rates in the world of 3.2% [90], effects of climate change causing temperature increase and unpredictable rainfall along with secondary problems such as floods, unexpected droughts, disease outbreaks have only exacerbated the problems and continued to make the poor even poorer [63, 64]. Energy and electricity access has a direct impact on developing an area, yet, Uganda has one of the least electricity supply and distribution networks only contributing about 1% of the total energy options in current consumption. Less than 20% of Ugandans (majorly in towns) have access to electricity. Less than 10% of the rural areas which cover more than 80% of the total population have electricity access [77, 83, 85, 88, 89]. Besides the desperate situation to grow the energy and electricity sector, Uganda is challenged with urgently adjusting to its intended means of mitigation against climate change, at the same time providing quick solutions to its population to improve their livelihoods and income in order to be able to adapt to the rapid changes of climate change.

Uganda has several mechanisms to address issues of energy access and bringing development to the people. Such bodies as the Rural Electrification Agency (REA) have a mandate to provide policy advice to the rural electrification board, ensure operationalisation of Uganda's rural electrification strategy, plan and administer the Rural Electrification Fund (REF) [86]. But such several mechanisms and targets by the government have so far yielded very little results [80].

Building of energy systems is an ongoing process in Uganda, however, building an integrated conceptual self-sustainable closed system within which clean energy is produced in a sustainable manner and at the same time, the local population is not only gaining several long term sustainable skills, an income for personal livelihood improvement, but also ability to forever be able to access and afford this generated electricity individually, is currently non-existent. Such a system has not yet been created in Uganda and many of the neighbouring African countries. Creation of such a system would require utilisation of energy engineering skills to design a techno-economically suitable electricity generation system, along with knowledge base on climate change mitigation strategies and adaptation requirements in the facilitation of faster development.

The Bamboo plant is now becoming very famous for being one of the top solutions to quick rural economic growth, mitigation of climate change and as a viable energy source due to its numerous unique characteristics. Uganda has however not yet embraced it fully and there is no record of work that has been done to exploit its energy potential.

1.3 OBJECTIVES

General Objective

To assess the techno-economic feasibility of a bamboo Biomass Gasifier Power Plant (BGPP) for rural electrification of Bududa district within an innovative sustainable rural development concept.

Specific Objectives

1. To design an innovative economic concept for income generation within which the BGPP can be apart.
2. To estimate the energy demand (the load) of Bududa district in Eastern Uganda, and estimating the rated power output of the BGPP
3. To estimate the required bamboo biomass to meet the load as well as the required land cover of the bamboo plantation
4. To assess the technical requirements for the BGPP in order to meet the load of Bududa district.
5. To determine the economic feasibility of this BGPP by assessing the Levelized Cost of Electricity, and the investment analysis parameters (Net Present Value, Internal Rate of Return and Payback period)

1.4 SCOPE OF THE STUDY

The study is meant to find out whether it is techno-economically feasible to design an electricity generation system for a rural location in Uganda, based on gasification of bamboo plant material and waste, in presence of an integrated sustainable economic model utilising only the bamboo plant to create skills, jobs and income for the people and at the same time benefitting the environment in this era of climate change.

The thesis

- Identifies a location best suited for the bamboo based economic development concept in Uganda which is Bududa district indicating the reasons why
- Estimates the required electricity Load of this Bududa district and the size of the required Bioenergy Gasifier Power Plant
- Proposes a sustainable innovative bamboo based concept for Bududa rural development that ensures sustainable provision of feed for the gasification plant, as well as a sustainable source of income for the local people to make the generated electricity affordable to an otherwise would-be extremely poor population.
- Investigates the current availability of bamboo plant in Uganda and its possible use in rural development and utilisation as a potential bioenergy source for electricity generation using gasification technology.
- Assesses the required technical parameters to meet the load and the economic feasibility of the BGPP

This thesis is therefore a mix of research, innovation in energy and sustainable development as well as techno-economic assessment of bamboo based bioenergy technology for rural electrification.

1.5. RESEARCH QUESTION

Is it technically and economically feasible to run a bamboo based Bioenergy Gasifier Power Plant (BGPP) for rural electrification within a bamboo based integrated sustainable economic development concept?

1.6. HYPOTHESIS

It is technically and economically feasible to run a bamboo based Bioenergy Gasifier Power Plant (BGPP) for rural electrification within a bamboo based integrated sustainable economic development concept

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2.0. INTRODUCTION

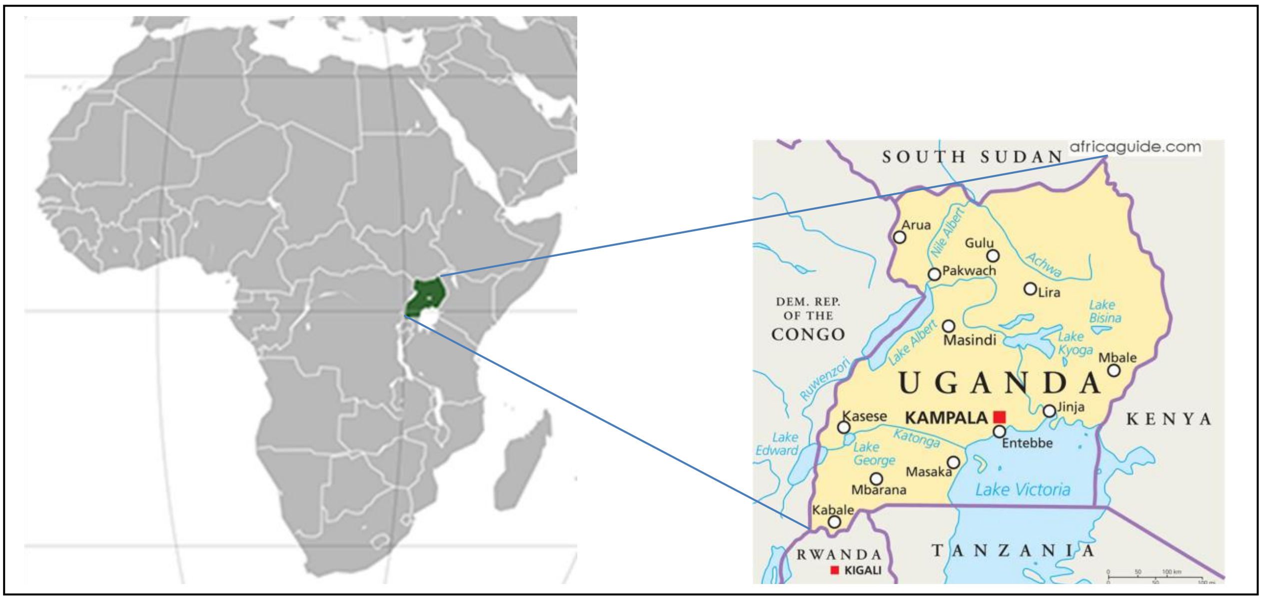
This section gives an overview on the background state of Uganda and its energy situation. It shows the current state of Bamboo plant for sustainable development, its significance in the era of climate change and as an energy crop. In addition, it gives a brief introduction to gasification systems, their application for rural electrification and the state of gasification technology in Uganda. Background information on utilisation of bamboo biomass for gasification technology is also discussed.

2.1. THE GENERAL STATE OF UGANDA

2.1.1. Location, Climate and Topography

Uganda is a land locked country covering total country area of 241,038 Km^2 in the East-Central Africa, west of Kenya and East of the Democratic Republic of Congo [60]. The country is crossed by the equator, and is located between latitudes 4^0 N and 2^0S and longitudes 29^0 and 35^0 E. *See Figure 2:1* Uganda, the heart of the great lakes region of Africa is surrounded by three: - Lake Albert, Lake Edward and Lake Victoria. Uganda lies within the Nile basin, almost completely. Uganda includes within its borders about half of Lake Victoria (the largest lake in Africa) and several other lakes. About 18.23% square Km of Uganda is covered by water [60]. It has tropical equatorial climate with generally two dry seasons (December to February, June to August) and a semi-arid climate in a small part of the North-Eastern region of the country [60]. The country's average temperature ranges between 22.4 and 23.6 ºC with a maximum of 28.5 ºC [69].

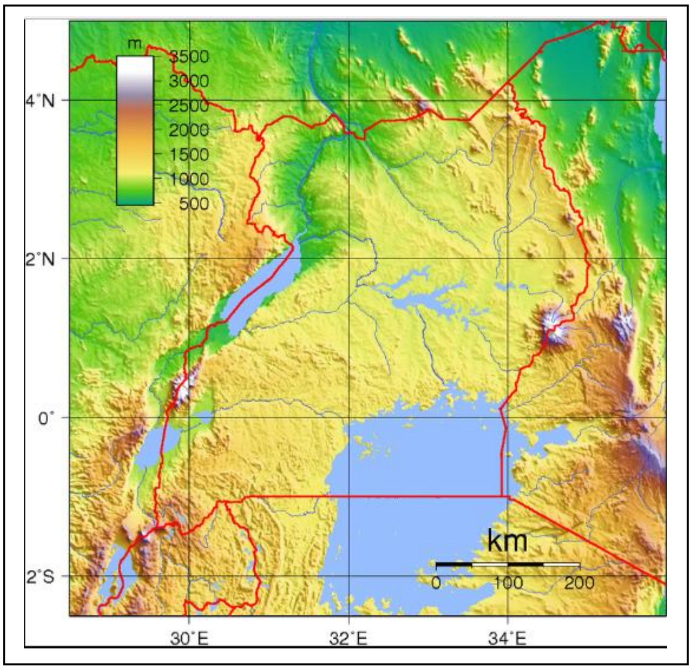
Figure 2:1: The Map showing Location of Uganda in Africa



Source: [66, 67]

Depending on the exact location however, temperatures within Uganda can peak at 29ºC and on rare occasions/places at 30ºC. The terrain of the country is generally mostly plateau with a rim of mountains [60]. *Figure 2:2* indicates the topography of Uganda [68]. Generally, Uganda is geographically described as a fertile well-watered country with many lakes and rivers [60].

Figure 2:2: The map showing topography of Uganda



Source: 68

2.1.2. Population

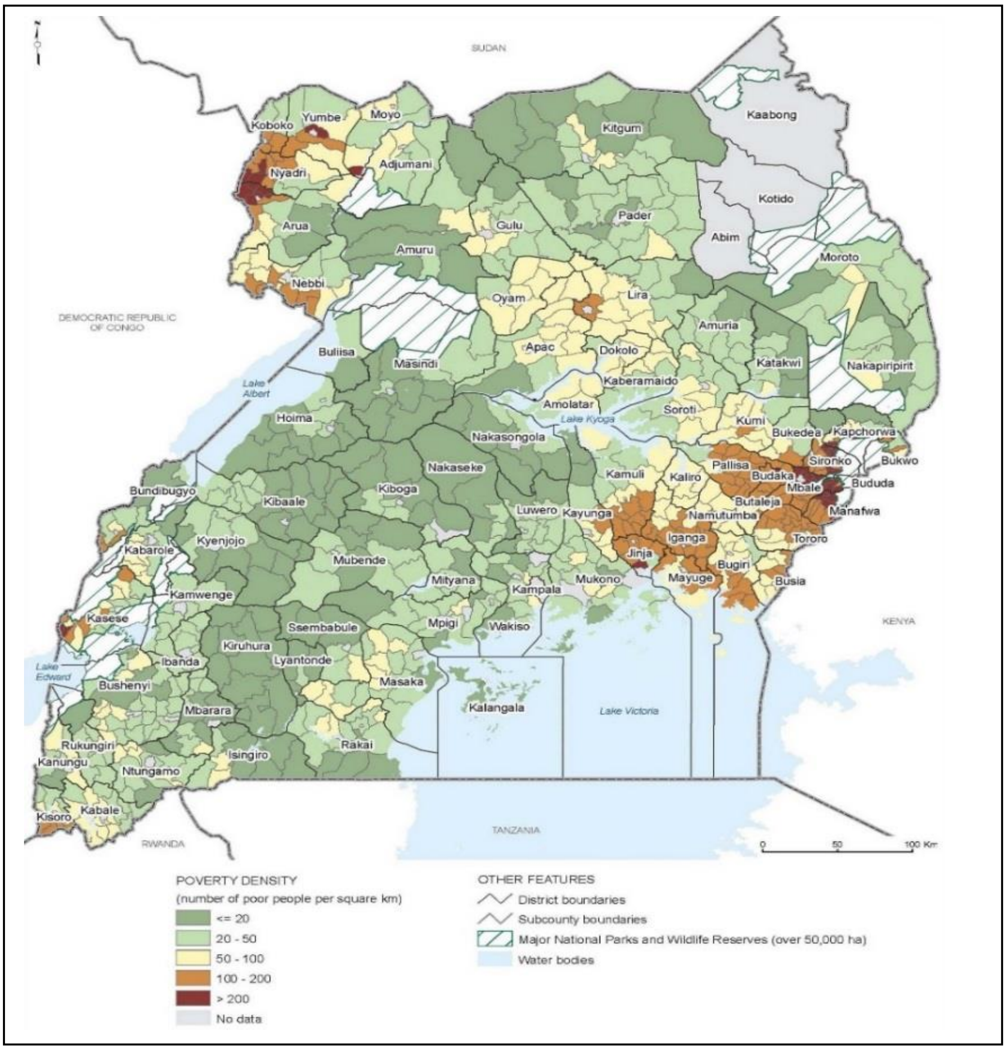
As of 2015, the population of Uganda was known to be about 39Million [74] with almost half of the population aged below 15years. United Nations estimates that as of May 2017, the population of Uganda was 41,448,659 people and with a median age of 16 years [72]. Uganda's population growth rate over the last decade was 3.2% per year [90], while the world average is about 1.2%. The Uganda Bureau of Statistics (UBOS) predicts that Uganda's population may grow to about 90 million by the year 2050.

2.1.3. Economy

Uganda's substantial natural resources include a wide area covered by fertile soils, regular rainfall, mineral deposits such as copper, gold, among others, and oil deposits. The most important economic sector is Agriculture and coffee currently accounts for the bulk of export revenues [70]. The industrial sector is still very small and depends on imported inputs like equipment and oil [70]. The overall productivity of the industrial sector is hampered by other supply side constraints but especially underinvestment in the agricultural sector that still relies on rudimentary technology [70]. Industrial growth is held backwards due to high costs of infrastructure, low levels of private investment and depreciation of the Ugandan shilling [70].

With a GDP of 25.61 billion (2015 estimates), GDP per capita of $2100 in 2016, Uganda was ranked 167th out of the 181 countries ranked based on GDP per capita [70]. The GDP growth was estimated by World Bank data to be 5.1% in 2015 [91]. Poverty in Uganda is understood as living below USD 1.90 per day which is known as the national poverty line [74]. *Figure 2:3* shows a map indicating the spread of people living below the poverty line in 2005 [61].

Figure 2:3: A map showing the number of people below the poverty line per square km as of 2005



Source: [61]

Poverty levels have been decreasing in Uganda at a high rate. In 2006, 31% of the Uganda population was living below the poverty line and by 2013; this proportion had decreased to 19.7%. Favourable prices and weather were assumed the key factors that led to this by increasing creation of income from agricultural produce [71].

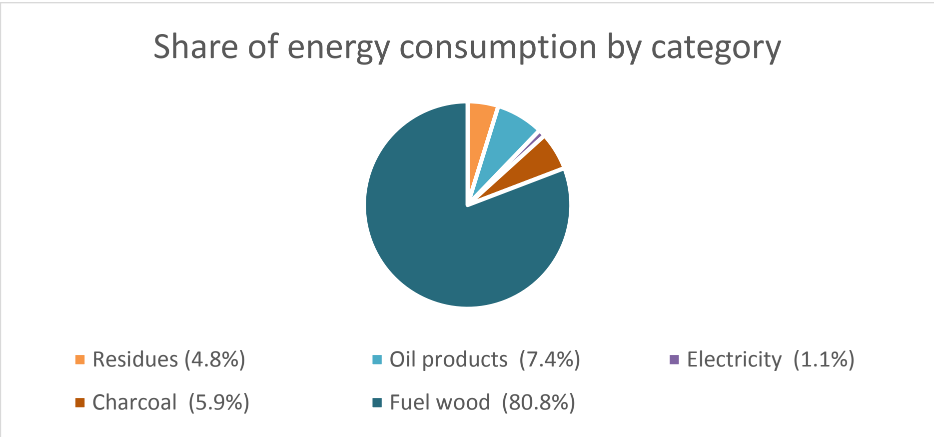
There is high rate of un-employment within Uganda. As of 2014, youth unemployment stood between 64% and 70% [73]. It was estimated that around 30% of institutionally qualified youth fail to find employment. The situation is even worse for the un-skilled and semi-skilled youth. There is still a lot of rural-urban migration especially by the youth who would rather not engage themselves is subsistence farming, a common practice in the rural areas [73]. In the urban areas, unemployment encourages higher crime rate, drug abuse and other activities such as gambling [73].

2.1.4. General State of Energy in Uganda

Efforts to increase economic growth in Uganda have encouraged more focused attention on strengthening its electricity sector. The speed at which this target can be achieved is dependent on how Uganda chooses to pursue new energy sources to transform especially the rural areas that cover over 80% of total population [80].

As of 2013, Uganda's energy supply was dominated by fuel wood use with very little electricity supply as expressed in *Figure 2:4* below [77]. As of 2010, 5% of all Ugandan household had access to electricity [80, 81]. In rural areas especially, where more than 80% of the population reside, access to electricity is less than 3% [77, 80, 82]. Electricity and petroleum/oil products are what is mainly considered commercial, and not biomass. Trading in biomass used is mainly considered informal and at times illegal.

Figure 2:4: Uganda's Energy use by category as of 2013



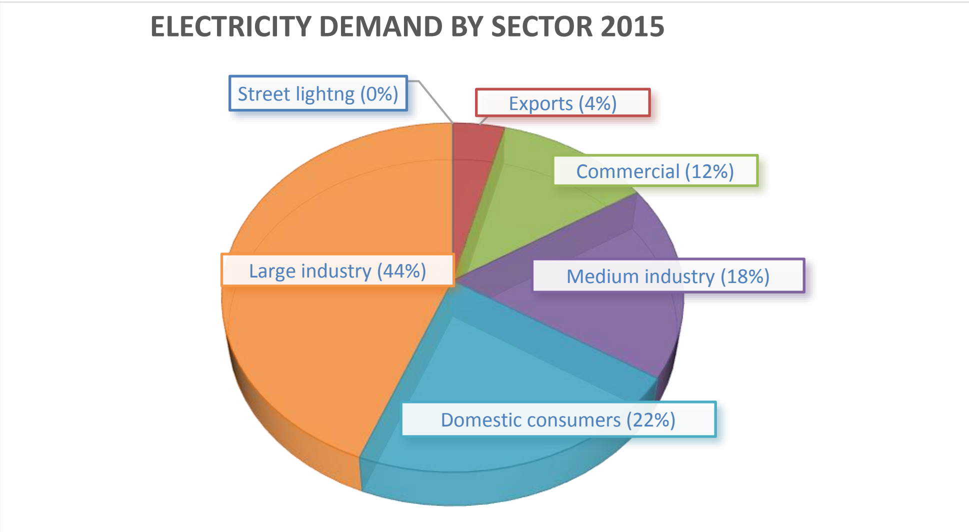
Source: [77, 83]

The electricity supply is estimated to be around 1% compared to other categories of energy use and is mainly supplied from hydro power stations within Uganda [77, 80, 83, 104]. Uganda has one of the lowest per capita electricity consumption in the world with close to 215KWh per capita per year (Sub-Saharan Africa's average: 552 kWh per capita, World average: 2,975 per capita) [88]. Electricity access was estimated to be about 18.6% of the population as of 2012, [89].

As of 2014, Uganda had an installed electricity generation capacity of 851.53 MW with a peak power system demand of 500MW and a firm capacity of 496 MW that varies according to the prevailing hydrological conditions. The total grid electricity supply was 3,203 GWh in 2014 [85]. The government of Uganda plans to increase the installed capacity by additional 2500MW by 2018 [85].

The rate of growth of Uganda's electricity demand is estimated at 10% per annum [85]. Countrywide, electricity is majorly utilised in the industrial sector, followed by domestic consumption such as households [105]. *Figure 2:5* below indicates the energy demand by sector distribution by 2015 [105]. In order to be able to successfully boost this sector and address the electricity crisis, Uganda has put several measures in place besides the plan to install additional hydropower facilities. Hydropower facilities however take time to be fully commissioned yet the electricity demand is growing fast [80].

Figure 2:5: Distribution of electricity demand within sectors as of 2015

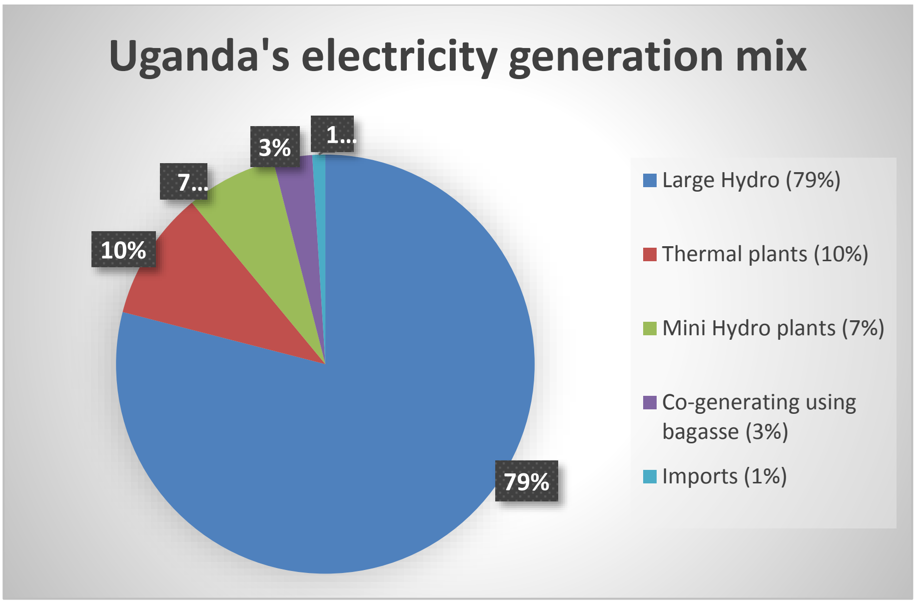


Efforts to boost the rural electrification sector brought into existence the Rural Electrification Agency (REA) strategy and plan with a primary objective "To achieve an accelerated pace of electricity access and service penetration to meet national development goals during the planning period and beyond" [84]. This plan targets an electricity access level of 26% of the rural population in 2022 [84]. Several other innovative schemes for rural electrification must be looked into urgently, in order to achieve such an objective.

2.1.5. State of Renewable Energy in Uganda

Uganda already depends largely on renewable energy with limited use of fossil based energy majorly from imported products. *Figure 2:6* below shows Uganda's electricity generation mix as of 2012 [104, 105]. It is clear that 99% of electricity generated in Uganda is through clean energy sources. The country's energy sector boasts of enormous renewable energy potential, abundant energy resources (biomass, hydropower, geothermal, wind, solar) fairly well distributed throughout the country but remain under exploited. The energy resource potential of the country includes an estimated 2000MW of hydro power, 200MW of mini-hydro, 450 MW of geothermal, 460 million tonnes of biomass standing stock with a sustainable annual yield of 50 million tons, about 5.1 to 6 kWh/m2/day of solar energy, and about 250Mtoe of peat (800MW), [86]. Installed power capacity is dominated by hydropower and currently stands at about 850MW including 100MW of thermal power, [87].

Figure 2:6: Electricity generation mix of Uganda as of 2012



The contribution of renewable energies to the bigger energy sector in Uganda has not yet been fully harnessed. Uganda's nascent energy sector is characterized by low levels of modern energy consumption and heavy reliance on biomass energy mainly utilised in traditional forms [86]. While the government of Uganda has put in place some long-term measures to address the current energy deficit and thus meet the country's long-term needs, many times the efforts have not realised the expected impact. Power outages have impeded the economic progress of the country [86].

The government is now focused on renewable energies with a view to reducing the overwhelming electricity supply deficit. National statistics indicated that 80% of Ugandans reside in rural areas and predominantly use rudimentary and inefficient technologies in their energy consumption. The government deduces that investment in the renewable energy sector would go a long way in satisfying the general electricity demand in the country. Currently, the country relies mostly on Hydro power for electricity generation [86].

In a bid to encourage energy production, in 1999, Uganda realized the need to attract private capital to its energy sector and reformed the power sector allowing for private sector participation. As a result of these reforms, Independent Power Producers (IPPs) are also currently participating in electricity generation, [87].

Several institutions are involved in the energy sector of the country, each with its own mandate. These institutions are involved in management, regulation, rural electrification, issuing licences, transmission, electricity sales, management of transmission lines, electricity production, and promotion and facilitation of the private sector energy investment in Uganda. The key institutions are the Ministry of Energy and Mineral Development (MEMD), Electricity Regulatory Authority (ERA), Rural Electrification Authority (REA), Uganda Electricity Transmission Company Limited (UETCL), Uganda Electricity Distribution Company Limited (UEDCL), UMEME Ltd, Uganda Electricity Generation Company Limited (UEGCL), Electricity Disputes Tribunal, Uganda Energy Credit Capitalisation Company (UECCC), and the Uganda Investment Authority (UIA) [86].

2.1.6. Biomass and Bioenergy Technology Development in Uganda

Uganda and especially its vast rural areas have a lot of marginal agricultural land un-suitable for food crop cultivation that can be employed for growth of woody crops a source for energy feedstock [80]. Unfortunately, bioenergy technology adoption and development is still very low in Uganda. Biomass is considered backward since it is used majorly in traditional forms such as cooking for household, commercial and public institutions [77]. Clean forms of biomass use and technologies are not yet well known or understood [75]. Also, the expected high costs of operations for modern energy conversion systems for biomass have contributed to their minimal utilisation [76].

In 2015, a policy brief on biomass technology by the ministry of finance, planning and economic development of Uganda stated that biomass in Uganda is a potential significant source of modern and clean energy/electricity [75]. In 2013, biomass residues (crop, animal and forest) were estimated to have total energy potential of 258.29 PJ/year [76]. It was also estimated by the policy brief that about 51 million tonnes of biomass are available for sustainable harvest for bioenergy production within the whole country [75]. Available forms of biomass are tree biomass, bush, papyrus and reed, farm level vegetable waste such as sorghum, cotton stalks and maize, agro-processing vegetative waste (bagasse) and grass/forbs. Tree biomass is the major contributor with the highest share of biomass potential at 26.3 million tonnes followed by the bush supply having biomass potential of 10 million tonnes [75].

The brief indicates that biomass is abundantly available for supply of bioenergy systems because Uganda's soil and climate support relatively faster rates of growth of biomass. However, in order to use modern technology bioenergy conversion systems, demand for tree-biomass may outstrip the supply. It is postulated that diversification of other forms of biomass to boost the available tree biomass supply has high potential as well [75]. Besides, Uganda pledged to increase forest cover from 15% to 18% by 2021 and 24% by 2040 [90].

A study by Buchholz et al. (2010) concluded that for Uganda, fuel wood demand created for bio-power is marginal (83Kg of dry wood per person per year, however if this biomass contribution was towards modern biotechnology systems, it would make a significant difference in the living standards of the people [80]. The study also concluded that since Uganda has only 0.4 ha arable and pasture land per capita and is a net food importer, biomass intended for bio-power systems should only be restricted to marginal sites or combined with agriculture [80].

2.1.7. Uganda and Climate Change

As of 2013, the World Bank data reports that CO2 emissions per capital of Uganda were 0.1 metric tonnes [91].

Uganda is highly vulnerable to climate change and variability because its economy and the wellbeing of people rely heavily on Climate. The rural inhabitants of Uganda who are over 80% [65, 90] of the population of Uganda still depend on rain fed agriculture [63]. Uganda therefore, is one of the countries that is being affected by climate change in several ways one of which and highest in rank, is the rising temperature. Estimates indicate human induced climate change could increase especially the average temperatures of Uganda up to 1.5ºC in the next 20 years and up to 4.3ºC by the 2080's [63, 64]. Temperature changes are expected to cause significant implications for water resources, food security, natural resource management, human health, settlement and infrastructure [63, 64].

Besides temperature rise, it is also predicted that changes in rainfall patterns and total annual rainfall amounts will occur, but these are less certain in comparison to temperature changes [63, 64]. Uganda's climate may become wetter on average with more unevenly distributed rainfall occurring more extremely or more frequently. Uganda could also possibly have more frequent or severe extreme climate events like droughts, floods, storms and heat waves [63, 64]. *Table 2:1* highlights the expected effects of climate to Uganda in detail.

Table 2:1: Expected impacts of climate change to Uganda

Impact		**Mechanism of impact**
Water	Change in river flow regimes	Higher temperatures and melting of Rwenzori glaciers temporarily increasing and then reducing flows in the Semuliki river downstream
	Water scarcity	Higher temperatures, evaporation and recurrent drought leading to stress, higher demands for water, conflict, and biodiversity loss. Partially implemented water resource regulation system hands legal access to water to the powerful
	Flooding	Higher 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
Health	Malaria	Extension into higher or once cooler areas with temperature increase where resistance may be low
	Water Bourne Diseases	Flooding is associated with diarrheal disease including cholera epidemics, particularly where sanitation is poor and in slum areas
	Respiratory Diseases	Associated with prolonged dry spells
	Malnutrition and famine	Associated with lower food production and insecurity, particularly with widespread damage brought by floods and droughts
Agriculture and food security	Seasonal rainfall change	Erratic onset and cessation of the rainfall seasons. Shorter rains. Crop failure or lower yields of staple foods like beans, cassava, maize and matoke; reduction in traditional varieties; and more crop disease Additional agricultural workloads – particularly women

	Higher average rainfall, high intensity events	Crop damage and soil erosion
	Pastoralists	Increase in rainfall in semi-arid areas could be beneficial, given mobile to take advantage of the rains. Droughts reduce viability of cattle corridor and precipitate conflict; there is expected Lower milk production therefore.
	Fisheries	Changes in nutrient cycling and loss of spawning brought by temperature and water level change reduce productivity
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 extinction	As niches are closed out by shifts in climate regime
	Transport links and settlements	Damage to bridges, roads, telecommunication and buildings during flood and storm events
	Energy	Changes in Lake level reducing flows available for power generation. Higher energy costs and energy poverty with knock on implications for charcoal use, deforestation and land degradation
Economy	Coffee	Uganda's primary export crop. Robusta sensitive to higher temperatures. Too much rain reduces flowering, which reduces production and also effects drying of beans. Diseases, pests and mould, hit both production and quality.
	Food prices	Increase due to pressure on internal and international production capacity
	Tourism	Potentially in decline due to degraded environment and infrastructure
Poverty	Multiple	Exacerbated. Vulnerability increased
Insecurity	Nile flows	Changes in water balance and demand heightens competition, potential for conflict.
	Migration	In response to acute or chronic climate induced stresses

Source: [64]

2.2. THE STATE OF BAMBOO IN THE REST OF THE WORLD, IN AFRICA, AND IN UGANDA

2.2.1. Uniqueness of the Bamboo Plant

Bamboo, commonly defined as a particular taxonomic group of large woody grasses. Bamboo plants are known to have 1250 species with 75 genera most of which are fast growing and attain stand maturity within five years [1]. There are dwarf bamboos as little as 10cm in height but the tall species may attain height of 15-20cm, and the largest known bamboo such as the specie Dendrocalamus giganteus grows up to 40m in height and 30 cm stem diameter [1]. Bamboo plants normally grow in warm and humid conditions. They are found mostly in tropic regions but can naturally live in subtropics and temperate regions in all continents except Europe [2,4].

More than 1500 bamboo species exist in the world [20]. About 80% of these are found in tropical and subtropical Asia [28]. Africa has 43 species naturally growing of which 40 are found in Madagascar and the remaining 3 are found in mainland Africa [29]. Of the mainland Africa Bamboo, 67% were known to naturally grow in Ethiopia [30]. However, Ethiopia has only two indigenous bamboo species i.e the African Alpine Bamboo (Yushane alpine or Arundinaria Alpine) and the monotypic genus lowland bamboo Oxytenanthera abyssinica. These two species are found in other African countries but nowhere else outside the African continent [30]. They are indigenous to Ethiopia and endemic to Africa, confined to the sub-Saharan region.

Several studies on bamboo have made conclusions of the plants' efficiency in the era of climate change. A study in India on the thorny bamboo species, Arundinaria Callosa, concluded that bamboo is of utmost importance to the local people both from the angle of environmental protection and economic importance [3].

Bamboos naturally exhibit two types of growth patterns, Monopodial and Sympodial. Monopodial types such as species of "Arundinaria" are normally small sized and have long creeping rhizomes that can produce outgrowths every year. As they extend long they produce fast growing culms and outgrowths and can cover a wide area with thick population of new culms [3]. For example, most species under the genus of Arundinaria are altitude oriented. They normally grow at high altitudes and occupy the top of hills. They grow luxuriantly, occupy wide spaces and large populations [3]. On the other hand, Sympodial growth patterns are clump forming with pachymorph types of rhizomes and Caespitose in nature [3].

About 1500 different commercial applications of bamboo were identified in Asia. These applications were divided into the broad categories of Construction and reinforcing fibres, textiles and board, Paper, and Food, [1]. Bamboo is also important for Agriculture and has roles in biodiversity conservation especially in regions where it grows naturally [14]. Bamboo is also useful in heavy metal clean-up of the soil as the plant uptakes a considerable amount of heavy metals during its growth. Bamboo therefore has the potential to decontaminate polluted land a process known as phytoremediation [4]. Bamboo forests have also been indicated to stabilise steep slopes and water ways, prevent soil erosion and contribute to waste water management [18].

Gupta and Choudhury [14] put forward that in spite of the fact that bamboo and its products can contribute substantially to the environment, not much systematic attempts have been taken to make use of the highly valuable properties of bamboo and its products at the advanced technical and scientific levels [14]. It was stated that the main reason for this neglect was more due to ignorance about the multitude properties of bamboo and its products and their importance to multi facet integrated development through its use as first of all, a bio-energy crop, and other uses such as food crop, environmental amelioration, a substitute of wood, as a material for infrastructural development, as environmental friendly housing and building materials, as a renewable energy and fuel source, as a herbal medicinal plant, as a controller of eco system damages, and for overall integrated development [14, 15, 16].

Gupta and Choudhury [14] lists 10 out of a total of 13 specific activities undertaken for eco-development for which bamboo use can be a major player. These 10 listed activities include; - improved collection and use of non-woody products, improved dry farming techniques, Efficacious water harvesting, Soil conservation measures, Preferences to cash crops (pulses, oil seeds, spices, cotton, medicinal plants, commercial bamboo plantations etc.), Agroforestry, Sericulture-Horticulture-and Apiculture, Ecotourism, Development of Infrastructure, and, Cottage industry and handcrafts. Bamboo therefore has strong direct and indirect linkages with conservation of biodiversity in general [14]. A model was thereafter suggested for Tripula (India) looking at the utility of bamboo and its products at two very distinct levels of domestic uses, and of commercial & industrial usage.

Bamboo is considered an exceptional plant when it comes to provision of oxygen into the atmosphere. Fisher [17] suggested an “Oxygen Oasis”, a completely new, innovative way to increase oxygen emission by 35% and help combat pulmonary disorders such as asthma all based on the bamboo plant. It is stated that Bamboo has superior properties that set it apart from other green plants such as shade trees and perennials in the case of urban environment. Bamboo emits 35% more Oxygen than other plants and therefore has great carbo sequestration properties. Yet again, it replicates quickly, has minimal water requirements, grows in sun or light shade, thrives in temperate zones and can stay green year-round [17].

Growth of bamboo

Bamboo is known to be the fastest growing perennial plant [29, 31]. Once the rhizome root system is established, new bamboo shoots attain full height (6-8m) and diameter (4-8cm) within 2-3 months [31]. Some species of bamboo are mature and ready for utilisation after 2-3 years [32]. Bamboo is known to flower towards the end of its lifetime (14-50 years in some species) and then dies soon after. Because of this, for example Ethiopians who live in the bamboo growing areas consider bamboo flowering as a "disease" [30].

Most bamboos regenerate successfully using culm cuttings. For Oxytenanthera abyssinica species however, propagation would preferably rather depend more on seeds than on vegetative propagules [24]. This is because of difficulties that were discovered in raising planting materials of Oxytenanthera abyssinica species [25, 26].

Bamboo forest plays a vital role too in environmental amelioration, bio-diversity preservation and soil and water conservation and also has waste purification potential [21, 22, 23]. Bamboo growth and utilisation has the potential to reduce pressure of utilising slower growing plants and trees.

2.2.2. Contribution of Bamboo to Significant Economic Growth in Communities

Bamboo is one of the most famous plants internationally for rural development and transformation. Tropical Asia has done a lot of work on bamboo utilisation. In Nepal, Bamboo is used in more than 180 ways [36]. More than 300 machine-intensive bamboo-processing factories were established from 1985 to 1992 in peninsula Malaysia [37]. Bamboo was already widely used in large quantities for pulp and paper production in India by 1991 [38], China by 1994 [39], Indonesia by 1980 [40] and other Asian countries. Bamboo pulp is known to be high grade, and the chemical recovery problems arising from a high silica content were solved by desilicification by 1980 [41]. By 1982, in Burma, bamboo was already extensively used as roofing material [42]. Good quality activated carbon can be produced from Bamboo [43]. Excellent quality particle board that meets Type 1, British standards, requirements is produced from bamboo [44].

Bamboo has also been actively used in Asia, at household and cottage-industry levels, to produce products such as mats, ladders, sticks, hand tools, pipes, brushes, scaffoldings, umbrellas, toys, sports goods, musical instruments, arrows and spears, fishing rods, caps, flower pots, baskets and so many other items since before the 1980's [20, 36, 41]. In this way, rural people have always been able to satisfy their own needs and also to supplement their income. Bamboo has also been used as a preferred material for shade construction in form of props to support the growth of agricultural crops like tomatoes, bananas, and flowers, and also to support plant nurseries. Bamboo shoots are a very popular food in Asia and wherever else bamboo grows in the world like Africa. The bamboo shoot industry is big in Asia where they are not only consumed as food, but also sold off by local farmers to generate income [110]. The nutritional value is known to be comparable to many other commercial vegetables [45].

Specific case studies

1) In China

China is currently heading the exploitation of bamboo. Over 80% of bamboo products are produced in China. This region has been showing the way in developing a true "bamboo-based economy" [108]. Bamboo has been developed there as prime feedstock for high-end commercial products for export, whereas residues and inferior qualities are used for lower-value bulk processing [108].

A study was done on a poor and mountainous county, the Tianlin County in the Guangxi Zhuang Autonomous Region of China to find the contribution of bamboo to household income and rural livelihoods [113]. The county government in partnership with the city of Guangzhou and a private company introduced and implemented a bamboo-based poverty alleviation program between 1997 and 2007 [113]. The contribution of bamboo based income in comparison with other sources of income such as crop based income (*annual crops grown on household land designated as agricultural land, and also includes income from fruit orchards*), livestock based income, and forest-based income, off-farm income (*income from transfers, household business and wage income*), and fish & environmental income was done [113]. Much as crop based income contributed the largest share of total income, it was mostly for subsistence and food security and not for cash. 93% of total Bamboo income was cash form making bamboo the second highest contributor of cash after off-farm income [113]. This study showed bamboo cultivation and utilization in Tianlin

County to be the most important source of cash among the entire farm based income generating activities (Crops, Livestock, other forest materials, fish and environment). The study attributes bamboo’s significant contribution to household cash to the recent industrialization of the bamboo sector. Bamboo was found to be the single most valuable important source of cash for the villages within Tianlin County that depended on it, while the other villages that did not depend on it either specialized in other forms of earning cash income or languished in poverty with very low cash incomes. The study also found out that both the villages that had long established bamboo sectors, and the villages that had recent creations of the bamboo sector through the government bamboo programs both successfully utilized bamboo as the forest based cash crop at the time of the study. Regardless of how and when the bamboo industrialization process began respectively [113].

2) In India

In India, Bamboos generate large rural employment in the management of bamboo forests, harvesting, collection, transportation, storage, processing and utilisation of bamboo. A study done on the basis of bamboo production and its uses in India estimated that a total of 432million workdays and Rs 13 billion (approx. 201 billion USD) in wages was generated annually [111].

3) In Bali

A case study in Penglipuran, Bali showed that bamboo is used as some form of bank by the farmers and owners on bamboo groves. The Penglipuran village is surrounded mostly by bamboo owned individually. Bamboo is an established crop in this village and there is sufficient market for all the 13 species in this are especially in construction. Village is home to many crafts makers and traders in bamboo products used both internally and externally.

The owners of the Penglipuran bamboo forest are among the richest in the community. Individual households look on crops as bank accounts where crops from arable land are viewed equivalent to a current account used to meet day-to-day needs for both subsistence and cash. Bamboo plantations are however perceived as savings accounts, used to meet emergencies and long-term investments such as children’s education [109]. Saving bamboo created a shortage in supply to an extent that the people of Penglipuran village usually source for bamboo and its products from neighbouring villages [109].

4) In Colombia

Just like China, in Colombia, a good marketing potential for mature culms (1 mature stem of bamboo) for the building industry exists [108]. Harvesting of a bamboo culm with basic processing such as preservation, producers of the bamboo culm were estimated to earn 12 dollars per culm for the construction industry in the housing market [108]. With an estimate of 1000culms per hectare per year [108], this can attract an income of 12,000 dollars per year with one hectare.

5) Ethiopia's bamboo situation

Ethiopia is one of the spearheading countries in Africa in Bamboo growth and development and has done more extensive work on bamboo studies. Ethiopia also has the same species as those of Uganda growing in similar conditions.

Ethiopia for example has a pure natural bamboo forest, the largest in Africa with over about 1 million ha, of which 85% of this land is covered by Oxytenanthera abyssinica [21]. This species is endemic to Tropical Africa [20].

In Ethiopia, the average annual stem increment of the unmanaged natural bamboo forests is 8.5-10 tonnes (t) of oven dry matter per ha [34]. This is indicated as a higher production rate than reports from bamboo forests in tropical Asia and elsewhere [27,28]. It is therefore concluded that it is possible to harvest about 3 million tonnes per year of oven-dry biomass on a sustainable basis from the 1 million ha of bamboo in Ethiopia; assuming selective harvest for bamboo plants of 3 or more years of age. Embaye [30] concludes therefore that this is sufficient to supply part of the particle board, fibreboard, pulp, furniture, construction, and energy requirements of Ethiopia.

As of 2000, the utilisation of bamboo in Ethiopia was very low limited mainly to hut (tukul) construction, fencing, and to a lesser extent production of furniture, containers for water transport and storage, baskets, agricultural tools, beehives, household utensils and various artefacts [22, 35]. The low level of utilisation within Ethiopian people was pinned towards bamboo's susceptibility to biological ad physical deterioration, and thus a short durability of bamboo products was expected. Various treatments are however available to increase Bamboo products' service life, but, people are un-aware of these technologies [30].

Bamboo supplements food requirements. The shoots and boiled rhizomes are consumed as food in Ethiopia. In 1999, drought resistant crops among which was Bamboo (in particular the low land species) were encouraged to minimise the effects of recurring drought [30].

Embaye (2000) [30] advised practical demonstrations to be the most effective way to demonstrate and convince people and that bamboo based research and development is urgently needed. Promotion of bamboo based investments and creation of markets is important. He also advised workable incentives and appropriate support, in the form of extension services, would be needed to accelerate this process. Links in the bamboo production, management, processing, manufacturing, end-product distribution, and utilisation chain, would have to be established, strengthened and maintained, using functioning markets.

2.2.3. Bamboo in Uganda

There are 2 known naturally growing bamboos in Uganda: - Arundinaria alpine/ Yushania Alpina (a.k.a highland bamboo) commonly found in Western Uganda in national parks of Rwenzori and Mt. Elgon regions, and Oxytenanthera abyssinica (a.k.a lowland bamboo) which is commonly found in Northern Uganda in Moyo and Kitgum districts.

Banana et al. (2001) [123] reported that Echuya natural forest reserve in Western Uganda located at high altitudes of 2270-2570m above sea level, covering 34Km^2 has about 11 tree species of which 53.2% was bamboo (Arundunaria alpine)

A number of other species have been introduced, are currently being grown for several other reasons, and are thriving in many areas of Uganda. There are several owners of medium scale bamboo farms known as bamboo groves. One notable bamboo grove owner and seedling seller is located in Masaka, Uganda and is known as the "Bamboo Eco resort" growing several types of Bamboo such as Bambusa Vulgaris Vitata (yellow bamboo), Bambusa Tulda, Dendrocalamus Asper, Bambusa Balcooa, Phyllostachys Nigra (a.k.a Henon), Phyllostachys edulis (a.k.a Moso), and Bambusa long internode. Nabyeya Forestry College in Masindi is another notable place where Bamboo is being grown. Economically, Moso bamboo is one of the most important bamboo species in the world with applications such as bamboo flooring and bamboo shoots for consumption [108]. Moso bamboo was noted as a key species for rural and industrial development [108].

Several farmers from around the country are buying seedlings and doing small scale bamboo projects. In 2017, the Bamboo eco resort in Masaka sells each seedling within price range 3650 to 5000UGX onsite. Dendrocalamus Asper seedlings are gaining fame among Bamboo farmers because they are commercially preferred for their huge size and use in construction industry. D. Asper commercial seedlings are sold at an average cost of 4000-5000 UGX. Some commercial bamboo grove owners also offer assistance to interested Bamboo farmers to establish bamboo groves. Many of these species can be used for Energy purposes along with other uses such as construction, food, feed, fence and handicraft [107]. Makerere

University for example has constructed structures with bamboo as a demonstration project meant to assure people that bamboo is a good and durable material for construction of beautiful houses [142].

Figure 2:7

Figure 2:7: Pruned Clump of Bamboo at the Bamboo Eco Resort, Masaka, Uganda. June 2017.

Figure 2:8:

Figure 2:8: One of the Bamboo Groves at the Bamboo Eco Resort in Masaka, Uganda. 2017.

Figure 2:9

Figure 2:10

Figure 2:9 and Figure 2:10: Bamboo at Nabyeya Forestry College Masindi, Uganda. 2017.

Figure 2:11

Figure 2:11
Dendrocalamus Asper bamboo species

Source: [146].

Figure 2:12

Figure 2:12
Clump of Yushania Alpina (Highland bamboo) species

Source: [146].

2.2.4. Bamboo, a Significant Source of Bioenergy

Several literature sources identify bamboo as the fastest growing source of biomass on earth with an unsurpassed regeneration potential [4,5,6]. Bamboo has several other characteristics that make it ideal as an energy crop and may make it useful for energy plantations [5]. Once properly set up, a bamboo plantation needs little care due to an extensive underground root system of roots and rhizomes. This system assures a regular regeneration of harvested plants above ground and also protects scarcely vegetated soils from wind or water erosion [5, 7]. Bamboo may not be grown on optimal agricultural land as it can withstand a certain level of pollutants [4]. A bamboo plantation requires 5-7 years to achieve full maturity. During this time, management is considerably inexpensive in terms of effort and costs. It's known that only during the first 2 years, maintenance costs mostly for weed control and possibly use of organic fertilisers may be required. But once the plantation reaches full maturity (5-7years), it maintains itself [4]. Harvested bundles of bamboo can be kept for at least 3 months [8,9], this combined with an optimal harvesting season of 6 months (from October to March) means that bamboo can be supplied as raw material to the industry for about 8-9 months in a year. This offers a possibility of a nearly year-round/ steady supply of biomass for energy production [4].

Truong et al. 2014, [2] gave a report, discussing the Bamboo biomass potential, particularly in the Vietnam context providing an overview and assessment of the feasibility of bamboo plantation specifically for energy production. It was indicated that Bamboo biomass has great potential to be an alternative for fossil fuel and can be processed in various ways including thermal or biochemical conversion processes to produce various energy products such as charcoal, syngas and biofuels. Bamboo chips are a suitable fuel for fluidized bed combustors and spreader stoker boilers. Bamboo can be adapted for briquette production and gasification using the same procedures as for other species such as pine tree or eucalyptus [4].

Literature provides that Bamboo biomass has both advantages and drawbacks in comparison to other energy sources. It has better fuel characteristics than most biomass feedstocks and is also suitable for both thermal and biochemical conversion pathways. The drawbacks of bamboo biomass include establishment, logistic and land occupation [2].

Hunter 2002 [19] points out that bamboo is increasingly used as a raw material for the production of countless articles but also as an energy source for cooking and heating, where there is no alternative thus making it a frequent substitute for wood [19].

The physical-chemical characteristics of bamboo make it a good biomass fuel for classic combustion processes. Bamboo is composed of easily harvested woody tissues containing cellulose, hemicellulose and lignin with an average calorific value of 18.3MJ/kg, which falls within the range of wood species of 18.2 to 18.7 MJ/kg [5, 10]. *Table 2:4* shows examples of fuel properties of some bamboo species. Bamboo as a biofuel source is therefore similar to other woody fuels with the exception of mineral content, which is higher (2.5% dry basis) for bamboo than for wood (1% dry basis) [4]. However, bamboos have Nitrogen and Sulphur content lower than that of other potential bioenergy plants, leading to a smaller exhaust of the pollutants nitric oxide and sulphur dioxide [5]. A comparison was made between fuel properties of some bamboo species and other bioenergy crops [1] as in *table 2:2*. It was found that bamboo plant competes favourably compared to Miscanthus and Switchgrass, well known energy crops especially in for example USA and Japan.

Table 2:2: Comparison between selected fuel properties of Bamboo and other bioenergy crops

Fuel Property	**Bamboo (range of three Phyllostachys species)**	**Bamboo (species not given)**	**Bamboo (species not given)**	**Miscanthus (Miscanthus x giganteus)**	**Switchgrass (Panicum virgatum)**
Gross heating value (dry; GJ/t)	19.1-19.6	15.85	18.96	17.1-19.4	18.3
Moisture content (%)	8.4-22.6 (samples analysed after shipping)	10.4 (at harvest)	2.94 (after drying)	15 (at harvest)	15 (at harvest)
Ash content (%)	<1.0	3.98	2.04	1.5-4.5	4.5-5.8

Sulphur content (%)	0.03-0.05	N/A	0.15	0.1	0.12

Source: [1]

Table 2:3: Fuel properties of other bamboo species from different sources

Bamboo species	**Bambusa Tulda**	**Dendrocalamus Asper**	**Bambusa Vulgaris**
Data source	[107]	[107]	[133]
Energy content (MJ/kg $_{dry}$)	18.61	17.92	
Moisture content (%)	37	37	
Ash content (in %)	1.92	4.23	2.86
Density	0.65 g/cm^3	0.77 g/cm^3	782.2 kg/ m^3
Volatile matter (%)			93.5
Fixed carbon (%)			4.17

It was discovered that the low ash and chlorine contents of some bamboo species that were tested makes them attractive for use in biomass combustion applications for electricity production [5]. The potassium contents of the samples were also found to be low; this is a good property for combustion applications of feedstock. In general, the alkali index of the samples (defined as kg alkali oxide per GJ energy content) was fond to range between 0.1-0.3, this is generally below the empirical limit of 0.17-0.34 kg/GJ known to cause adverse fouling and slagging in combustion systems [11, 12]. Studies have showed that Chlorine in in biomass increases the volatility of alkali metals during combustion [13]. The bamboo samples tested indicated low chlorine content which suggested that the potassium present in the bamboo biomass in unlikely to be volatile and therefore not problematic in terms of ash deposition [5]. The low chlorine content of the bamboo samples means that burning the bamboo biomass is unlikely to enhance high temperature corrosion in biomass combustion systems.

It was also reported that pyrolysis of bamboo biomass (90% stem and 10% leaves) at 487ºC resulted into approximately 70% of the fed material converted into pyrolysis oil (bio-oil) fit for use as a fuel [4,7].

Bamboo was also found to be an interesting material for producing charcoal. The calorific value of bamboo charcoal (31.66 MJ/kg) is equivalent to the calorific value of beech and poplar charcoals. The mass yield of bamboo (33% on initial anhydrous mass) was found to be higher than for wood (29% on initial anhydrous mass carbonised in the same conditions of temperature, residence time and heating rate. The production of non- condensable gases was also higher (26.5% vs. 18-20%), while the tar production was lower (42% vs. 50%). Bamboo was found to also have differences in volatile matter yield and composition due to the fact that bamboo carbonisation results from the cutinized inner and outer layers of bamboo culms. This particular structure of Bamboo limits the gases outflows from the solid to the surrounding environment. This makes it favourable for secondary pyrolysis reactions i.e. cracking of heavy tars, recombination of volatile carbon with the fixed carbon structure [4, 7].

An economic comparison between energy crops willow, poplar, Miscanthus and bamboo upon production in Europe indicated that Bamboo had the highest return on investment and the highest Net Present Value after 30 years [4]. Bamboo was considered equally useful (and potentially more interesting) as the other 3 energy plants.

The selection of ideal fuel wood species is based on its FVI calculated using calorific value, wood density, and ash content [134]. From the value of the FVI, *B. vulgaris* can serve as a replace for wood as biomass feed stock for energy generation [133].

A study in Belgium identified bamboo as a useful candidate to provide biomass for electricity production [4]. Pilot tests of bamboo growth in Ireland showed that Bamboo produced enough biomass even under adverse climate to make the plant economically an equal investment as other classic energy crops [4]. Moreover, Europe is not a native region for the bamboo plant.

Biomass yield does not differ between species of bamboo; however, moisture content and calorific values differ within different species. This makes some species more attractive options for bioenergy than others [46]. Species with lower moisture content and higher calorific value are preferable energy feedstocks.

Experiments showed that carrying out gasification of bamboo at lower temperatures and in presence of steam enhanced the quality of the syngas (having higher Hydrogen and Carbon dioxide content with limited Carbon dioxide). However, as temperatures of gasification increase, more Carbon dioxide is produced with less quality syngas unless a catalyst is used [47].

2.2.5. Challenges and Constraints with Bamboo

Bamboo plantation has been found to be challenging especially with failure to contain the plant within its designated plantation area due to the spreading rhizomes. This could especially impact the development of nearby ecosystems. This spreading factor has however been found easy to contain if taken into account from the start. Solutions such as use of commercially available polyethylene sheets put in the soil around the plantation at a depth of 50-70 cm, the rhizome overgrowth can be effectively blocked [4].

As a source of biomass, the annular structure of bamboo culms makes it a very aerated and bulky fuel if used in rings or sticks. This means that bamboo would burn quickly and would therefore require bigger combustion or gasification chambers to obtain the same heating rate. However, if bamboo culms are chipped, these drawbacks are avoided.

Land occupation; Just like other biofuels, Bamboo plantations would have to occupy land that could have been used for other activities such as agricultural cultivation. This poses a limitation to the bamboo resource. The best solution to this is utilisation of marginal lands instead of prime land intended for food, feed, forage, fibre or oilseed crops. Contaminated land for example with heavy metals, previously industrial areas. Bamboo plant could be used for phytoremediation of the land as a bio-accumulator for heavy metals [4]. This could help in cleaning up land for future purposes such as agriculture. Phytoremediation is known to be less expensive with its only disadvantage being that it takes a lot of time before all contamination has been cleared. Within this length of time however, the plant bamboo being used for phytoremediation can be used for other economic activities. Bamboo can also be grown on hilly areas prone to soil erosion that is making agriculture almost impossible in that region. It could be grown in semi-arid areas that have minimal utilisation especially in agriculture. It should be noted therefore that with correct choice of plants, a lot of terrain could obtain additional economic value.

Considerable labour inputs required to establish and harvest. Much as labour inputs for bamboo are low compared to food crops, harvesting of bamboo has been found onerous in many cases. It may require a considerable amount of labour force [109]. This however may be an opportunity for job creation.

Bamboo is considered un-fashionable in some societies and has a poor image especially among the wealthy [109].

There is **low degree of local knowledge** [109] about many of the bamboo uses and this would require a considerable amount of training and awareness if there is a plan to boost bamboo growth in a region.

2.3. GASIFICATION SYSTEMS

Gasification is the process of converting carbonaceous feedstock (solid fuel) into a combustible synthesis gas, or syngas, by partial oxidation in a net reducing atmosphere at high temperature. Syngas, from a complex set of reactions is composed of H_2, CO, CH_4, CO_2, H_2O, N_2, minor species, and tars [48, 52].

Gasification is also defined as the complete thermal breakdown of biomass into a combustible gas, volatiles, char and ash in an enclosed reactor or gasifier [118].

Chemistry of gasification

Typical gasification requires 4 processes and stages [118]: -

-Drying, because biomass for gasification requires moisture content of 20-30% before starting the process [118]

-Pyrolysis, decomposes biomass into gases (CO, H_2, CH_4, CO_2 and other minor ones), organic vapours, liquids (tar and oil), and solid carbon (Char) at high temperatures of 500 - 700°C. Char and Ash are the pyrolysis by products that are not vaporised [118].

-They partially combust with Oxygen in the air to create heat, and further facilitate gasification process [118].

-The last stage is the Boudouard reaction and the Water-Gas shift reaction which increase H_2 production [118].

The Partial Combustion

$$C\ (Char) + 0.5\ O_2 \rightarrow CO \qquad (1)$$

The Boudouard reaction

$$C\ (Char) + CO_2 \rightarrow 2CO \qquad (2)$$

The Water - Gas shift reactions

$$C + H_20 \rightarrow CO + H_2 \qquad (3)$$

$$CO + H_20 \rightarrow CO_2 + H_2 \qquad (4)$$

Oxidants of gasification

Three oxidants; air, pure oxygen and steam, are commonly used in gasifiers. A mixture of steam with either air of oxygen can also be used. Air blown gasification is known to have a disadvantage of atmospheric Nitrogen acting as a diluent (syngas contains about 50% Nitrogen), reducing the syngas heating value/calorific value but can fuel engines and furnaces [49, 52].

Steam blown gasification is preferable because of its main advantage being that greater syngas LHV of 15-20 MJ/Kg is produced [49]. Steam based gasification is also known to have tendency of showing superior carbon conversion (defined as the ratio of reactant carbon to carbon in the syngas $\eta_C = m_{carbon,gas}/m_{carbon,feed}$), [48,49]. However, steam blown gasifiers require an external heat source due to the overall endothermic nature of the process [49] in that steam would require being raised to reactor temperature.

Oxygen blown gasification produces a gas with medium calorific value (intermediate LHV of 10-12 ML/kg) [50], and is generally the cleanest syngas with regard to tars, and also contains no Nitrogen [52]. Oxygen blown reactors do not have the heating demands required in raising steam to reactor temperature, although, the oxygen separation plant can consume a substantial amount of energy. Oxygen blown gasification is associated with high costs and technology uncertainties especially for the case of small systems, with the scaling of air separation apparatus [49].

In terms of qualitative comparison, no clear advantage was found between air and steam blown gasification. This is because the greater LHV of steam process syngas could be offset by the heating duty to raise steam to reactor temperature. Therefore, both alternatives can operate in similar economic and technological feasibility [49].

If steam is chosen as the main oxidant, the steam/biomass ratio is an influential parameter on gasification reactions. A steam/biomass ration of about 0.6-0.7 w/w was found to produce higher energy and carbon conversion, greater gas yields and a gas composition favouring H_2 formation [48, 49].

Air and steam gasification media also have favourable operating conditions including relatively low temperatures used for biomass gasification can reduce the vaporisation of inorganic salts and heavy metals in comparison with direct combustion processes. Also, the chemical environment of the gasifier inhibits dioxin, furan, NOx, and SOx formation [49].

Another existing type of oxidant for gasification is "Supercritical water gasification" that could be viable for syngas production. This process operates above the critical point of water (22.1MPa/ 3205Psi and 374ºC). Actual operating temperatures could approach 1000ºC. The solubility of organic material in supercritical water gasification is known to improve contact with the gasification medium, enhancing product yield. The supercritical water gasification is known to produce negligible tar and boast η_c greater than 90% [49, 51].

Types of gasification systems

There are two major types of biomass gasifiers [52];

i) Fixed Bed Gasifiers (i.e. Updraft, Downdraft and Crossdraft)

ii) Fluidized Bed Gasifiers (i.e. Bubbling Fluidized Bed and Circulating Fluidized Bed)

Another type, Entrained Bed reactors have also been used for biomass gasification although not commonly [52].

Unlike Fixed bed gasification technology, Fluidised Bed gasification is a relatively recent development and its application has mostly remained limited to developed countries so far [52]. "Fluidised Bed" technology was invented in Germany by Fritz Winkler in 1921. He built a commercial air-blown fluidised bed gasifier of cross sectional area 12 square meters. This unit became operational in 1926and was used for powering gas engines. Fixed bed gasification technology on the hand, was established by 1900 [52].

Biomass gasification technologies in the industrialised world started to change with research and development efforts resulting in remarkable improvements in especially small-scale fixed bed gasifiers systems and also emergence of a new generation of technologies for large scale gasification plants. In the late 1990's, 50 manufacturers offering commercial gasifier plants in Europe, USA and Canada were identified [53]. 75% of these designs were of downdraft type, 20% were of fluidised bed type, 2.5% were of updraft type and 2.5% were of various other types [52, 54].

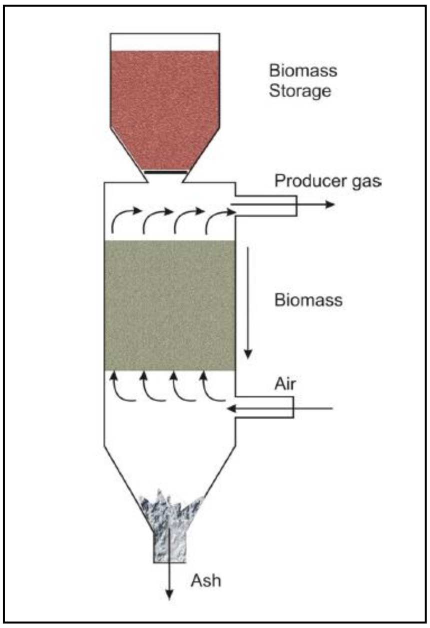
In the case of the developing world, biomass gasification is quite well established in china and India. This is due to the fact that they have maintained sustained efforts to improve gasifier designs through research and development and promotion of field applications. Otherwise, the energy crisis of 1973 generally affected progress of biomass gasification technology in the developing world. Around the 1980's to 1990's, gasification systems in the developing world faced a lot of technical problems particularly because of tar, and the low cost of fossil fuels. But as of 1990, 50 gasification plants were installed in Indonesia producing power (in the range 10-120kW$_e$) and heat (in the range of 400-900kW$_{th}$) [52].

2.3.1. Fixed Bed Gasifiers

i) Updraft gasifiers

The air enters at the bottom and the gases produced pass upwards and exit near the top. The exit stream contains combustible gases, water vapor, nitrogen from the gasification air, and tar vapours produced in the pyrolysis zone [52].

Figure 2:13: Schematic of a small-scale updraft gasifier



Source: [126].

ii) Downdraft gasifiers

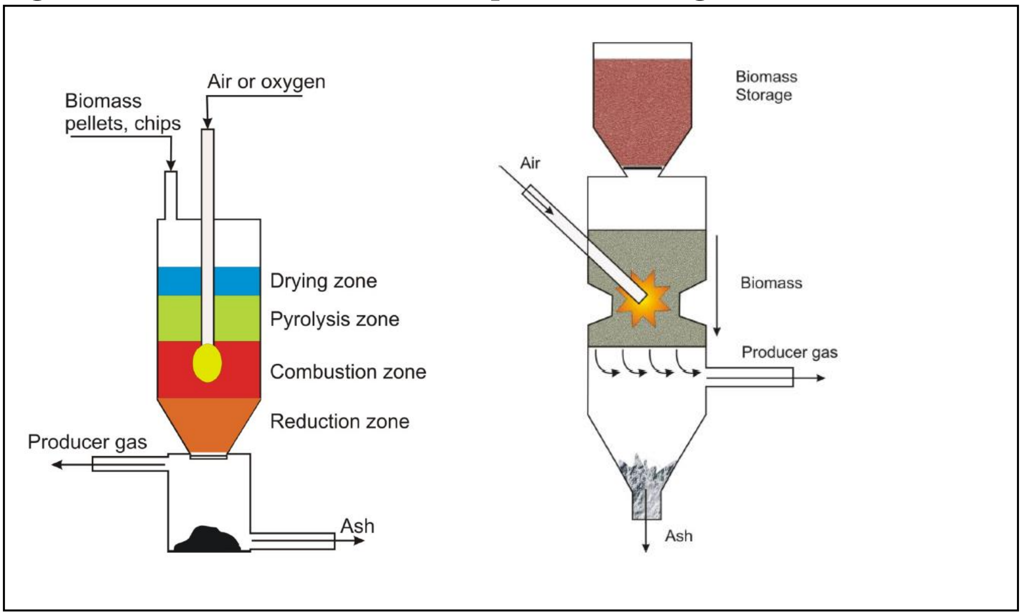
When biomass is fed into the gasifier, the constituent particles (e.g., chips and pellets) are dried by the heat in the gasifier, releasing steam into the gas phase. Further heating the dry biomass causes pyrolysis, i.e., breakdown by heat. First, volatile compounds desorb from the particles; then larger molecules, such as cellulose, hemicellulose, and lignin, start to decompose, emitting fragments into the gas phase. Finally, a carbon-rich porous structure remains, i.e., charcoal. If an oxidizer such as air or oxygen is used (the gasifier can also be heated indirectly), the released hydrocarbons and charcoal are partly combusted, forming CO2, CO, and water and releasing heat [126].

This released heat (or transferred if it is an indirect gasifier) is the driving force to all of the processes taking place in the gasifier. When the oxygen is consumed, reduction reactions take place in the hot environment. Those reactions are endothermic and bind heat from the environment. This means that the temperature drops in the gasifier due to the reactions [126].

Those reactions produce a gas mixture, producer gas, consisting of CO2, CO, H2, H2O, lower hydrocarbons (mainly CH4 and some C2 compounds) and tars as the main components. The exact composition depends on the type of gasifier and the mode it is operated.

The downdraft gasifiers produce much less tar than updraft gasifiers and are normally preferred for running internal combustion engines. However, with advances in gas cleaning and tar cracking using catalysts updraft gasifiers are also being developed for power generation [52].

Figure 2:14: Schematic of two example downdraft gasifiers



Source: [126]

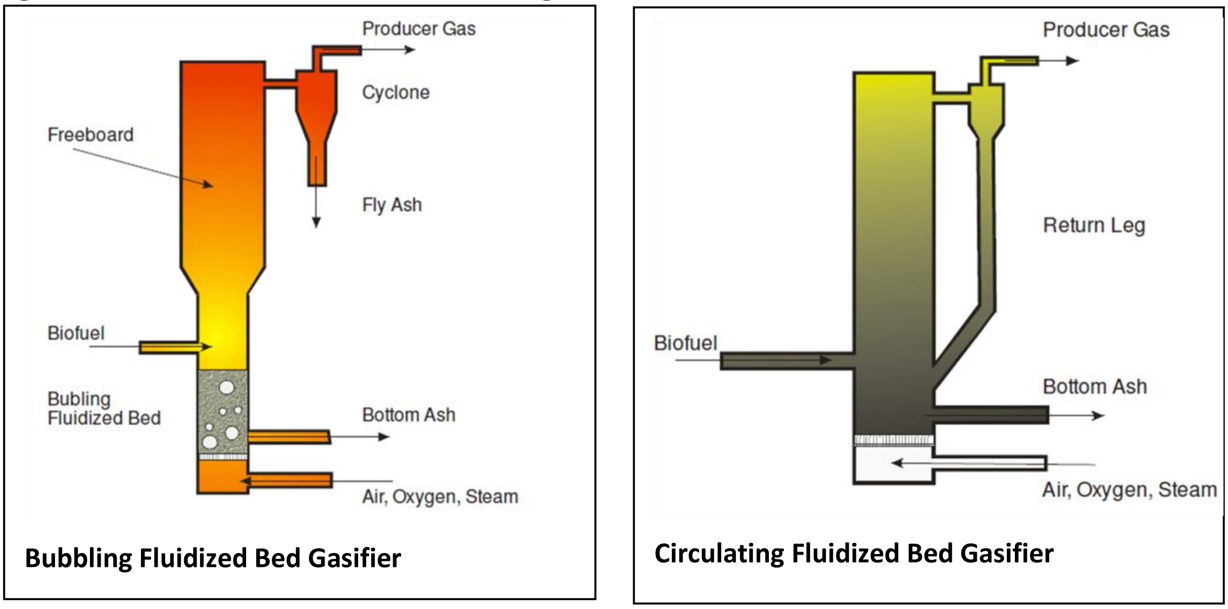
iii) Cross-draft gasifiers

The air enters through a nozzle and the gas flow is normal to the axis of the fuel bed. These gasifiers have simple construction but low tar conversion ability and have found limited application so far, mostly for small-scale charcoal gasification for producing power.

2.3.2. Fluidised Bed Gasifiers

Fluidized bed gasifiers are generally used for applications of larger capacities compared to fixed bed gasifiers, typically above 2.5 MW [52, 122]. They are more tolerant to feedstock properties than fixed bed systems [122].

Figure 2:15: Schematic of fluidised bed gasifiers



Source: [126]

i) **Bubbling Fluidised Bed (BFB) gasifiers**

These essentially consist of a bed of fine inert particles, such as sand, of size around 1 mm, through which a gas flows upwards. A part of the gas passes through the continuous particulate phase (consisting of particles and interstitial gas) of the bed while the remaining part rises through the particulate phase in the form of voids or bubbles [52]. Typical temperature in the bed is about 700°C to 900°C [116]. The feed, which is finely grained biomass, is introduced just above the distributor plate. The biomass first undergoes pyrolysis in the hot bed above distributor to form char and gaseous products due to devolatilization. The char particles are lifted along with fluidizing air and undergo gasification in relatively upper portions of the bed. Due to contact with high temperature bed, the high molecular weight tar compounds formed are cracked; thus, reducing the net tar content of the producer gas to less than 1–3 g/N m3 [116].

ii) **Circulating Fluidised Bed (CFB) gasifiers**

Circulating fluidized beds (CFB) is an extension of the concept of bubbling bed fluidization. In this case the velocity of the fluidizing air is much higher than the terminal settling velocity of the bed material. Thus, the entire bed material (biomass + inert material such as sand) is lifted by the fluidizing air. The exhaust of the gasifier is a relatively lean mixture of solids and gas. This exhaust is admitted into a cyclone separator where solids get disengaged from the gas and are returned to the bed through a down-comer pipe. Depending upon the solids concentration and size distribution either single stage or multi-stage cyclones are employed. Circulation of the biomass particles is carried out till the particles are reduced in size due to combustion/gasification. An advantage that circulating fluidized bed design offers is that gasifier can be operated at elevated pressures [116].

Applicability of the Fluidised Bed gasifiers

Much as Circulating fluidised bed (CFB) gasifiers are commercially available, they are not expected to be economically viable except in very large sizes greater than 40MWe which is even larger than appropriate for biomass based projects [122]. A demonstration of a 10MWe pressurised CFB gasifier using wood chip fuel during the 1990's in Sweden was done but discontinued after 3 years because it was un-economical [122]. CFB Systems are not usually considered below 30MWe and an upper limit of single units as of 2011 was 450 MWe (coal fired) or 300MWe (100% biomass-fired) [122].

On the other hand, Bubbling Fluidised Bed (BFB) Gasifiers are a well-established commercial technology used for capacities ranging from a few MW to 100MWe. They are also normally used to burn biomass of lower quality with high volatile matter [122].

2.3.3. Gasification of agricultural residues

Agricultural residues such as bamboo, rice husk, coconut residues, corncob and straw, in comparison to wood, are considered more difficult to gasify. Except for some (such as coconut residue), agricultural residues are generally known to have low bulk density and therefore would present a problem of flow within gasifiers having throat [52]. However, it was pointed out that gasification of problematic fuels should not be ruled out if it is available abundantly and involves little or no transportation distance [57].

Another fact is that some important residues like rice husk have much higher ash content compared to wood. For such fuels, downdraft gasification appears to be more attractive than updraft gasification, because besides lower tar content of gas, lower temperatures at the grate would reduce ash slagging [56].

Agricultural residues were classified into four categories on the basis of their suitability for downdraft gasifiers as shown in the *Table 2:4* below [55].

Table 2:4: Assessment of agricultural residues as fuel for a gasifier [55].

Very good fuel	Potentially good fuel	Potentially troublesome fuel	Verified troublesome fuel
Alfafa straw (cubed)	**Bamboo**	Barley straw (slagging problems observed)	Barley straw (slagging)
Almond shells	Coconut shells	Coconut husks (some sources claim high ash content)	Bean straw (slagging)
Corn cobs	Coconut wood	Corn fodder (slagging problem)	Cotton trash (slagging)
Olive pits	Coffee hulls	Oats straw (high ash content)	Cotton stalks (slagging)
Peach pits	Peanut husks	Rice straw (high ash content)	Rice hulls (slagging)
Prune pits	Soybean hulls	Sugarcane, bagasse (possibility of high ash and silica content)	Safflower straw (slagging)
Walnut shells	Wheat straw (some varieties with low ash)	Rye Straw (high ash content)	
		Wheat straw (varieties with high ash content)	

This table above created in 1981 indicates that bamboo was considered a potentially good fuel.

2.3.4. Syngas Cleaning

Syngas is a gas mixture composed of primarily Hydrogen (H_2), Carbon monoxide (CO), and very often some traces of Carbon dioxide (CO_2).

Syngas may require cleaning to remove impurities especially particulates (soot, char, ash), tars, sulphur containing compounds (H2S, Carbonyl sulphur) and Nitrogen containing compounds (NH_3) [118]. *Table 2:5* below summarises the main gasification contaminants and their potential problems.

Table 2:5: Examples of producer gas contaminants

Contaminants	Examples	Potential problem
Particles	Ash, char, fluid bed material	Erosion in gasifier and prime mover
Alkali metals	Sodium and Potassium compounds	Hot corrosion
Nitrogen compounds	NH_3 and HCN	Local pollutant emissions
Tars	Refractive aromatics	Clogging of filters and other fouling
Sulphur, chlorine	H_2S and HCl	Corrosion, emissions

Source: IRENA (2012) [139]

Particulate matter (soot, tar, ash) is normally removed through methods such as cyclone, filtration, and electrostatic precipitation [118].

Tar removal methods are

-High temperature destruction (most important for commercial syngas applications). When the temperature of raw product syngas is increased (between 1100 and 1300°C) and by addition of oxygen, all compounds in syngas are cracked and destroyed [118].

-Catalytic tar reduction is performed in the raw gas after the gasifier at elevated temperatures (400 -850°C), and usually Nickel based catalysts are used. Major disadvantage is sensitivity of catalysts for impurities in raw gas can easily lead to catalyst poisoning of gas components. Catalytic poisoning occurs when poisoning gas molecules in the gas stream (like sulphur) adsorb irreversibly onto the active sites of the catalyst.

-Physical removal such as scrubbing and electrostatic precipitation of tars can be done at lower temperatures below 450°C where tars are condensed and removed with high efficiencies [118].

Sulphur compounds can be removed by

-Burning the sulphur contaminants to create SO_2 and then application of wet scrubbing technologies such as Limestone scrubbing to remove the SO_2 from the gas stream. SO_2 reacts with limestone to produce gypsum to be separated from gas stream.

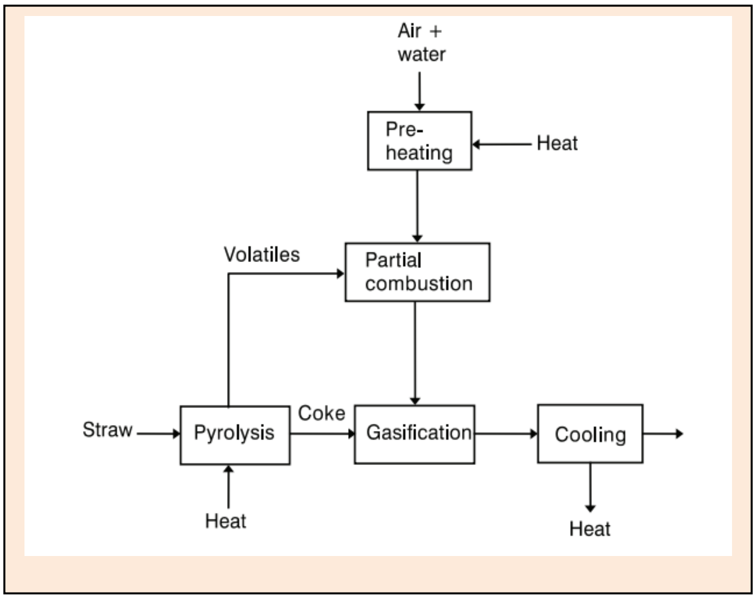
-Physical methods using van der waal force between gas molecules and an adsorbent that captures sulphur contaminants

-Chemical absorption of sulphur with metals as chemical adsorbents using covalent bonding of gas molecules onto the metal surface, to create compounds such as ZnS and FeS.

Multi stage gasification systems

It is claimed that a multi stage gasification system illustrated in *Figure 2:16* below [52] separates volatiles produced during pyrolysis from charcoal. At the end of the process, product gas practically contains very little tar and can be used to run an engine after cooling and removing the particulate matter.

Figure 2:16: Illustrative diagram of a 2-stage gasification system



Source: [52]

As a result, therefore, the produced gas is essentially the product of charcoal gasification and has low tar content.

Tar being present in producer gas needs to be eliminated as far as possible if the gas is to be used in internal combustion engines or gas turbines. Large scale use of biomass gasifiers would therefore call for minimisation of impurities in the syngas [52].

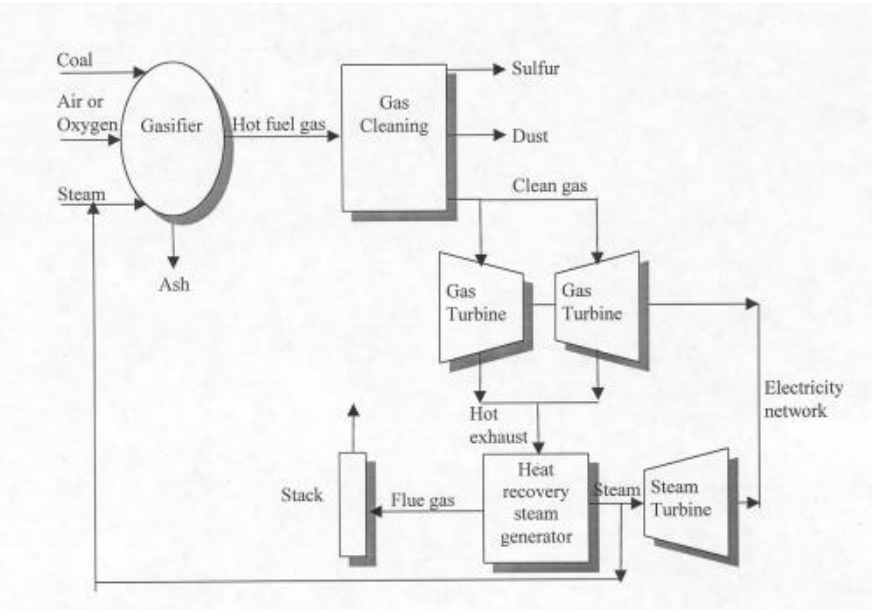
Syngas cleaning is also at times very necessary to increase system efficiency. Extensive studies on catalytic use under different conditions for hot gas cleaning were carried out even before the 1980's [52]. Catalysts are known to break down the primary volatile products of pyrolysis into smaller molecules; thus, tar reduction is accompanied by an increase in the amount of gas produced. Many studies were carried out on dolomite, limestone and nickel-based catalysts. [52]. Catalytic hot gas cleaning has improved the applications on power generation from biomass.

2.3.5. Integrated Gasification Combined Cycle (IGCC)

These are of most interest for specifically large-scale biomass gasification for power generation. Much as the IGCC has suffered some project failures before, it emerged as most promising power generation system from biomass in capacities above $5MW_e$. IGCC was in fact seen as the total final concept of a biomass-to-electricity system [52, 58].

The IGCC system operates in such a way that gas obtained from gasification is used to run a gas turbine. The exhaust from the gas turbine is used to produce steam in a heat recovery steam generator (HRSG); the steam thus produced drives a steam turbine-generator unit to produce additional power. An example illustration of an IGCC is given in *Figure 2:17* below. The gasification process can be carried out at atmospheric pressure. The atmospheric pressure system is simpler but less efficient compared with pressurized gasification [52].

Figure 2:17: Typical components of an IGCC system



Source: [59]

2.4. GASIFICATION SYSTEMS FOR RURAL DEVELOPMENT

In the case of Ugandan rural areas and many other underdeveloped countries, it is common to find a low and spatially scattered population settlement. The cost of extending the grid in such areas can pose a challenge even when the country happens to produce enough power for the whole country [80]. This encourages limitations of power supply to already established and grid connected urban areas while rejecting the majority rural areas. Rural locations therefore with low electricity energy consumption and dispersed demand require more innovative and flexible energy solutions [80].

Several literature sources indicate that gasifier based technology has proven to be robust and reliable under conditions of tropical developing countries [80, 117]. Several rural development projects especially in Asia are on-going based mostly on gasification technology. Ravindranath et al., (2004) [121] gives several reasons, some listed below, why among all Renewable Energy Technologies, gasifier based power generation holds most potential for meeting rural energy needs:

- *Technology maturity*: There are several designs and manufacturers that undertake planning and commissioning of small scale power systems and also provide performance guarantee.
- *Availability of different capacity scales* (such as 5, 20, 100, 500, 5000kW) of biomass gasifiers especially for decentralised applications
- *Feasibility of operating within different hours and periods*. Biomass gasifier-based systems can be operated from 1h to 24 hours a day depending on the load. The systems can be operated all year round every day if woody biomass feedstock is available with good storage systems. Other renewable energies like Wind and Solar do not provide such flexibility due to the intermittencies of the resources.
- *Flexibility of installation in any location/village*: The biomass gasifier systems can be installed and operated in any village where biomass can be availed, grown or stored. Such flexibility may not be possible with other renewable energies such solar, wind, micro-hydro and biogas systems.
- *Socio-economic benefits*: Biomass gasifier based systems can create a diversity of job opportunities for both skilled and less skilled people in feedstock production, transportation, processing, operations, and maintenance of gasifier plant parts.

A comparative study of technical options for biomass conversion to electricity concluded that the only two viable technologies for commercialisation of electricity production from biomass are (i) Biomass gasification coupled with an IC engine operating on Producer gas, and (ii) A boiler steam turbine route (or cogeneration) [116]. Of the two technologies, Biomass gasification was stated to be more suitable for distributed and decentralised electricity generation in remote villages [116]. Biomass gasifiers can be installed at practically any village where sufficient biomass is available annually to ensure smooth operation. A single biomass gasification unit with either updraft or downdraft design can generate up to 500kW power while a gasification station with fluidised Bed design has capacity of about 5MW [116].

In the case of Brazil for example, by 2004, the “Programa Luz para Todos” funded by the Brazillian Government was planning to start a campaign to popularise biomass gasification technology for rural electrification [52]. This move was to benefit communities like those located deep in the amazon region.

Jan Brandin et al. (2011) [126] states in his analysis that gasification can be an economically attractive alternative to diesel generated electricity for rural areas. Sustainable fuel wood supply is very important for the success of gasification plants, if business models for a complete gasification system provide incentives for farmers and entrepreneurs to provide biomass year-round, it would ensure sustainability. A degree of local control over all components of the system – fuel wood supply, conversion technology, and power distribution – would make a gasification system more likely to succeed in rural electrification projects.

It was postulated though, that gasification systems although running on potentially inexpensive wood fuel, they are characterised by high capital costs and long pay back periods which are bottlenecks to rural electrification efforts beyond applicability to large agro-industrial operations unless support credit schemes are in place [126].

2.5. STATE OF GASIFICATION IN UGANDA

Gasification technology is not yet widely used in Uganda [124]. Available literature reviews only two formerly existing gasification plants in the country; the 250kW rated system at Muzizi tea estate installed in 2006 and the 10kW system located on a farm in Mukono-Uganda, and visited in 2007 [124, 125,126]. Both systems used Eucalyptus tree as feedstock and were supplied by Ankur Scientific, India.

2.5.1. 250 kW Gasification Plant at Muzizi Tea Estate

Its location was away from the Uganda electricity grid connection yet; electricity was needed to dry tea at 80°C. Diesel generators were previously used, one of which was replaced by the gasification system [124, 125,126].

The fuel demand was met from a 99ha eucalyptus plantation. The eucalyptus wood was stacked manually and dried outdoor (air dried) for six months to a moisture content of about 15%. The fuel wood feeder was fed about every 20 minutes with approximately 60Kg of wood. Total fuel wood costs including establishment, maintenance, harvest, transport and manual stacking were estimated at USD22/oven dry tons, equalling the price paid to farmers who occasionally sell fuel wood to the plant.

The power conversion system was the GAS 250 system from Ankur Scientific, India. It was rated at 250kW net electricity output. However, the average power output is 87kW, far below the system's 200kW peak rated capacity.

The heat recovery unit is located at the exhaust and cooling cycle of the syngas engine. Maximum heat recovery is assumed to be 80% of the heat produced. However, actual heat recovery data were not obtainable due to missing control units. The operators expected to save 15% of fuel wood at the boiler due to the heat recovery unit at the syngas engine.
The system wood consumption was 1.6tons/MWh of electricity produced. Considering that eucalyptus has an energy content of 5MWh per ton, this means that the system conversion efficiency of the wood is just 15%. The total annual electricity output of the system is 381MWh, but with operation of only 6 days per week, with one un-operational day for maintenance and working 12 hours per day.

The system had the parts below: -

- a downdraft gasifier reactor of 400 kW_{th} with automated fuelwood feeder and ash and charcoal removal
- a cyclone filter to separate ash from the hot gas
- a gas cooling and scrubbing unit using water
- two parallel filter units each consisting of a coarse filter (wood chips) and two fine filters (sawdust, not shown in the figure) to allow constant operation even when cleaning the filters
- one cloth bag filter (not shown in the figure)
- a blower to move the syngas to the engine
- a 250 kW Cummins India syngas engine
- heat recovery units on the exhaust pipes and in the water cooling cycle of the engine

The system employed a minimum of about 11.5 staff members per day with 4 skilled and 8 un-skilled labour employees [126]. Work including, monitoring the system, feeding the feeder with wood, charcoal and sludge removal, filter cleaning, and monitoring of controls. *Table 2:6* indicates the parameters of the Muzizi tea estate system.

Table 2:6: Muzizi tea estate system performance and financial analysis

SYSTEM PARAMETER	**UNIT**	
Installed electricity capacity	kW	250

Internal electricity demand	kW	35
Internal (starter) electricity source		Diesel
Depreciation period	years	13
Average electric capacity	kW	87
Average Load factor		47.7%
Fuel wood consumption	odt/MWh	1.37
Fuel wood consumption	odt/year	469
Electrical conversion efficiency		14%-15%
Heat recovery rate		22%
Gross electricity production	MWh/year	363
Litres diesel saved/year	litres/year	71,328
Avoided CO2 emissions; from avoided use of diesel at generator	t/year	468
Financial parameter		
Alternative electricity cost (diesel-derived)	USD/KWh	0.22
Total capital costs	USD	495,198
Capital costs/kW installed	USD/kW	2,087
Operational costs	USD/year	48,030
Labour costs	USD/year	17,275
Fuelwood price	USD/odt	22
Fuelwood costs equivalence at 155 efficiency	USD/kWh	0.03
IRR		-13%
Payback period	years	-
Electricity production costs	USD/KWh	0.29
Diesel costs saved	USD/year	44,773

Source: [125].

The capital costs included: Feasibility study, building, gasifier, gas engine, shipping, customs duty, insurance, clearance, fuel wood processor, wood processing shed, installation and commissioning, additional electricity controls, and training. **Operational costs** included: land costs, generator fuel, maintenance material, hauling of wood from stacks, top up engine overhaul once in 5 years and major overhaul in every 4 years. **Fuel wood costs** included land lease, operations, transport.

It was concluded that the Muzizi Tea Estate clearly indicated the need for well-designed business models to manage the feedstock supply, conversion technology, and energy allocation components of gasification systems in Uganda [126]. It is necessary for the creation and support of energy service companies to in order to attract more systems within the country.

2.5.2. 10 kW Gasification Plant at Mukono Farm with Dual Fuel (wood/diesel)

This was a 100acre farm producing pork and Aloe vera. By the time of visit and assessment in 2007, the gasification system on the farm included a downdraft gasifier WBG 15 from Ankur Scientific, India, rated at a gas flow rate of 37.5 Nm3/h, a thermal output of 45kWh/h, and a biomass consumption of 12-15 kg (air-dried)/h [125]. This system (the gasifier, producer-gas processing units and generator) was funded by was financed by DeutscherEntwicklungsdienst (DED).

Biomass feedstock is Eucalyptus tree prunings from the farm with diameters of less than 2 cm. Twigs are cut by a circular saw to a length of 5 cm and air-dried for 3 months. A 12.5 kW Field marshall modified diesel engine produces three-phase electricity (10 kW max.) running on dual fuel mode (wood and diesel) with a minimum of 25% diesel content. The system is started by a car battery on 100% diesel. A blower is not required. The producer-gas is filtered through a water scrubber, sawdust, and cloth filter. The fuel mix is regulated automatically by the engine speed. Starting time is between 5 to 10 min. Waste heat is not recovered. The footprint was 4x4 m with another I0x4 m shed for storage and processing of the wood fuel). The water cycle for cooling and filtering contained 500I of water.

The system has a grid consisting of 30 electricity poles and 700m of wire connecting the farm house, pig stay and security lights.

The *table 2:7* below indicates the parameters of the system.

Table 2:7: Mukono farm system performance and financial analysis

SYSTEM PARAMETER	UNIT	Current use (wood 75% and diesel 25%)	If it used 100% wood, estimates
Installed electricity capacity	kW	10	10
System start-up		Car battery	Car battery
Depreciation period	Years	10	10
Average electricity capacity	kW	3.55	8
Average daily use		24%	31%
Wood-share of fuel		46%	100%
Wood cons (air dry9	Kg/kWh	3.73	2.19
Diesel consumption	l/kWh	0.18	0

Electrical conversion efficiency	Wood only/fuel mix	3%/6%	12%/n.a
Gross electricity production	kWh/Year	7,451	21,900
Fuelwood consumption	odt/year	17	29
litres of diesel saved per day	l/day	3.2	20
Avoided CO2 emissions	t/year	3.1	19.7
Financial parameter			
Capital costs including for grid installation	USD/kW	2,250	2,890
Alternative electricity cost (diesel-derived)	USD/kWh	0.56	0.39
Fuelwood price	USD/odt	0	22
Diesel price	USD/l	0.94	0.69
Fuel costs (wood and diesel)	USD/kWh	0.17	0.03
Electricity production costs	USD/kWh	0.78	0.31
Diesel costs saved	USD/year	1,097	5,037

Source: [125].

Fate of both gasification systems

These systems faced a number of challenges [125] some listed below

- they ran below rated capacities causing both economic and mechanical challenges for example the system conversion efficiency of the wood in the MIZIZI tea estate system was just 15%
- they suffered corrosion especially at the gasifier and filter systems which threatened long term viability
- the system at Mukono farm had limited means to monitor the wood-diesel mix, resulting in inadequate options to reduce diesel consumption and therefore production costs. At Muzizi Tea Estate, there was missing control units which prevented a rapid analysis of the quantity and quality of producer-gas flows.

As of 2011, both systems were decommissioned. The electricity grid was extended to the site of Muzizi Tea Estate rendering onsite gasification power production uncompetitive to grid electricity sold at \$0.12-0.16/kWh [125]. The Mukono farm system was decommissioned in 2008 when the farmer left the area and the gasifier system was transferred to the engineering department at Makerere University, Kampala. However, since early 2007, road-diesel prices in Uganda rose by nearly 30% from US$0.96 to US$1.22/l while other cost factors remained fairly stable. Revisiting the economics of the 2007 scenarios, the improved scenario at Muzizi Tea Estate (150 kW at 47.7 % load) would have produced an IRR of 27% instead of 11 % and a payback period of 5 instead of 8 years considering 2011 diesel prices. In the case of the Mukono farm system, a 100% fuelwood based gasifier producing 8 kWh at a 31% load would undercut 2011 diesel-derived electricity costs by 60%, yielding a cost of electricity of US$0.31 instead of 0.49/kWh [125].

2.5.3. Recent, Current state and Future Plans for Gasification Based Technology in Uganda

Nyabyeya Forestry College located near Uganda's Budondo forest has a 50kW electricity generation power system running on both diesel and with gasification of wood cuttings from the college's sawmill. The school saves 5.5 litres of diesel fuel that would otherwise have facilitated production of the same power capacity [130].

In 2011, a US based Taylor Biomass energy signed a collaboration agreement with a Ugandan company, Sesam Energertics Limited to construct a USD160million biomass gasification plant with capacity of 40MW power in Kampala, Uganda [127]. The system was projected to recycle at least 1,030metric tons of Municipal solid waste from Kampala per day [127].

In 2016 (December), Sustainable Energy Fund for Africa (SEFA) approved a USD 993,000 grant to a Ugandan firm, the Earth Energy Company Ltd to prepare a 20MW gasification power plant for Gulu district in Northern Uganda, to be add the generated power to the national grid [128, 129]. This grant was to facilitate feasibility studies, environmental and social impact assessment, a feed and detailed engineering design and project management activities. The project was expected to create 6,000 jobs and also provide 15,000 farmers with an additional annual income of USD 720 per person through sell of agricultural residue to the project [128]. This support by SEFA was a part of the African Development Bank (AfDB) efforts to support private investments in Renewable Energy in Africa. [128, 129]

2.6. BAMBOO BASED GASIFICATION

In Africa, there is currently no bamboo based gasification that has been done before. The utilisation of bamboo as a renewable energy source has not yet been studied extensively [136]. In Asia however, bamboo based gasification is ongoing. A study and assessment in

India on bamboo use specifically for gasification purposes into syngas and electricity concluded that gasification of bamboo and bamboo wastes from process factories has potential to produce both power and thermal energy [131]. Literature on this study gives below characteristics in *table 2:8* of Bamboo plant as a biomass source for gasification purposes.

Table 2:8: Characteristics of Bamboo as biomass feed

Bamboo plant characteristic	**Content**
Proximate analysis	
Moisture	13%
Volatiles (dry basis)	80.6%
Fixed Carbon	15.6%
Ash (dry basis)	3.9%
Elemental analysis	
Carbon	43.8%
Hydrogen	6.6%
Nitrogen	0.4%
Sulphur	nil
Other properties	
Calorific value	16.2 MJ/Kg
Bulk density	Approx. 300Kg/m^3
Ash deformation temperature	1300 -1350°C
Ash fusion temperature	1400 -1450°C

Source: [131].

The *table 2:9* below indicates the heat content of various biomass fuels in comparison with Bamboo. It can be concluded that bamboo relates well among potential biomass plants.

Table 2:9: Heat content of various biomass fuels (dry basis)

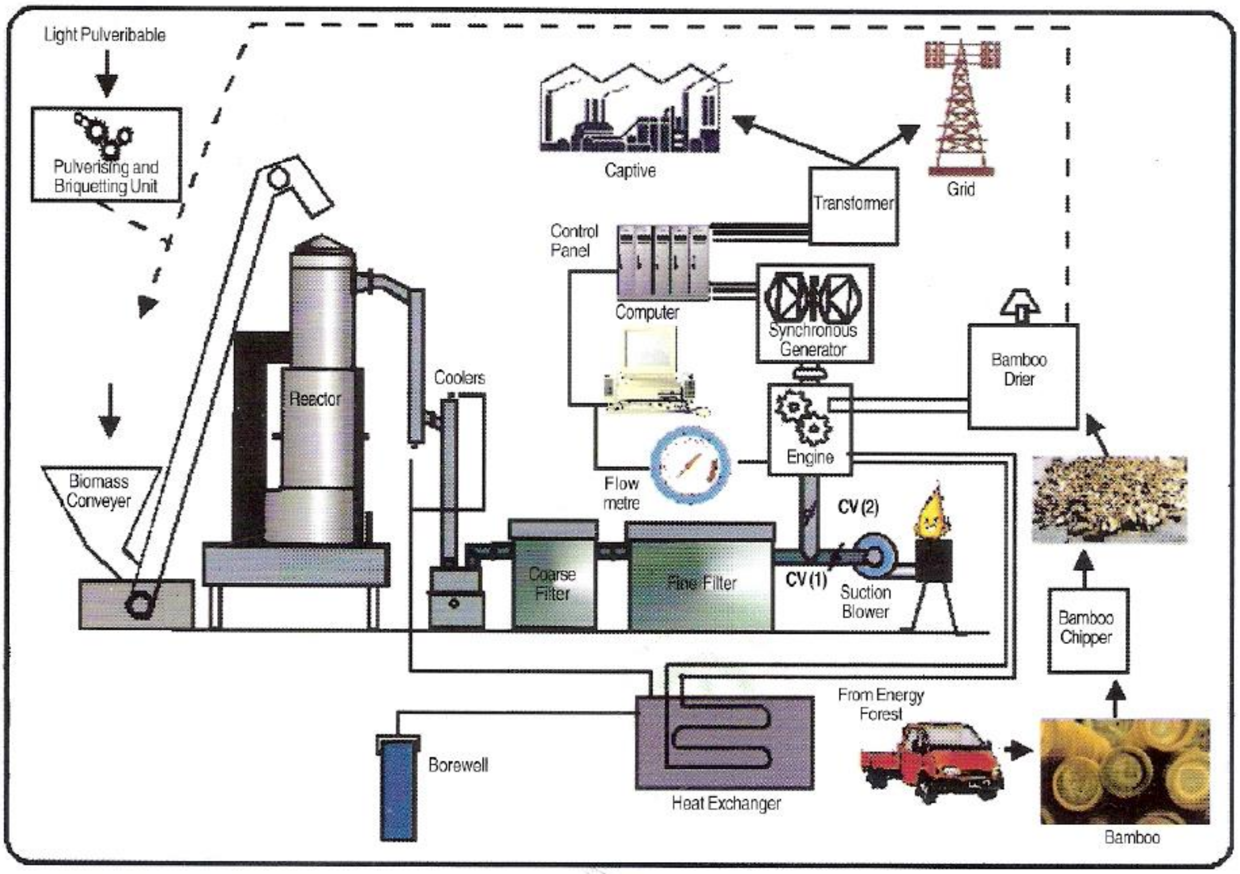
	Higher heating value MJ/kg	**Lower Heating value MJ/kg**
Agricultural residues		
Corn stalks/stover	17.6 – 201.5	16.8 – 18.1
Sugarcane bagasse	15.6 – 19.4	15 – 17.9
Wheat straw	16.1 – 18.9	15.1 – 17.7
Hulls, shells, prunings	15.8 – 20.5	

Herbaceous Crops		
Miscanthus	18.1 – 19.6	17.8 – 18.1
Switchgrass	18.0 – 19.1	16.8 – 18.6
Other grasses	18.2 – 18.6	16.9 – 17.3
Bamboo	19.0 – 19.8	
Woody crops		
Black locust	19.5 – 19.9	18.5
Eucalyptus	19.0 – 19.6	18.0
Hybrid poplar	19.0 – 19.7	
Douglas fir	19.5 – 21.4	
Poplar	18.8 – 22.4	
Maple wood	18.5 – 19.9	
Pine	19.2 – 22.4	
Willow	18.6 – 20.2	
Forest residues		
Hardwood wood	18.6 – 20.7	
Softwood wood	18.6 – 21.1	17.5 – 20.8
Urban residues		
MSW	13.1 – 19.9	12.0 – 18.6
RDF	15.5 – 19.9	14.3 – 18.6
Newspaper	19.7 – 22.2	18.4 – 20.7
Corrugated paper	17.3 – 18.5	17.2
Waxed cartons	27.3	25.6

Source: 139

The technical feasibility of using bamboo in gasifiers was tested and validated by the Indian Institute of Science, Bangalore. The gasifier operation was found to be smooth and consistent. Reactor pressure drop (which reflects the health of the reactor) was found to be satisfactory. No issue was reflected regarding Ash or Ash melting. There was presence of Hydrogen of around 20 - 23 % which indicates an energetic syngas. Producer gas composition was of reasonable consistency and quality. The contaminants were not different from other producer gas from other woody biomass [131]. *Figure 2:18* below is a process for bamboo gasification in India on a smaller scale using fixed bed gasifier [131].

Figure 2:18: Bamboo gasification using an Open top down draft gasifier



Source: [131].

Another study using experimental apparatus on bamboo gasification performance from Municipal solid waste was done in 2016 [132]. The experiments were to find out the effect of equivalence ratio (ratio of amount of introduce air into the gasifier to the amount of air required for complete combustion), the effect of gasification temperature, the effects of steam feedstock ratio, and the effect of Calcium Oxide (CaO) presence and on syngas composition, and the LHV of the bamboo in the MSW feedstock [132].

The equivalence ratio for bamboo gasification has to be maintained low in order to avoid decreased combustible gas components and a lower LHV as well as be able to minimize CO_2 yield [132].

Bamboo indicated an optimum gasification temperature of 700°C for the best syngas quality and the highest LHV of 6.22 MJ/Nm^3 [132].

CaO adsorbs CO_2 produced from the syngas; this increases the combustible gas components in the syngas while the yield of CO2 is decreased [132].

Wongsiriamnuay et al (2013) [136] did work on effects of operating conditions on catalytic gasification of bamboo in fluidized bed reactor. Temperatures tested in experiment were between 400 and 600°C, it was found that with increasing temperatures, the content of H_2 and CO decreased while the CO2 in producer gas increased. Using steam in the reactor in addition to air was found to increase the quality of the fuel gas by increasing the contents of H_2, CO and LHV. The presence of a catalyst (CaO) was found to increase the amount of H_2 and CO at higher temperatures.

CHAPTER THREE: METHODOLOGY

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3.0. INTRODUCTION

The methodology describes the case study location selected and factors that make it ideal for the bamboo based sustainable concept. This section describes the methods used to determine the answers to the research question and the solutions to the objectives.

The main data sources were; The Bududa district Local Government Statistical Abstract of 2012 [99], the "Techno-economic Analysis and Life Cycle Assessment of Bioenergy Systems" document by Shah et al., [138], "Gasification of Bamboo, Info-sheet" document by NMBA-India [131], "Costs of low-carbon generation technologies" (2011) by Mott MacDonald [122], and "GIS and rural electricity planning in Uganda" document by Elizabeth Kaijuka (2006) [102].

3.1. TECHNICAL ANALYSIS METHODOLOGY

The technical analysis involves the assessment of market viability and adaptability of technology, project service life, maintenance requirement, skill requirement for operation and maintenance, range of capacities available, ease of transportation and installation, adaptability in particular project conditions, access of material supply required for the set up, and, at times aesthetic and inherent risks [138]. A technical feasibility assesses the details of how the products and services will be delivered.

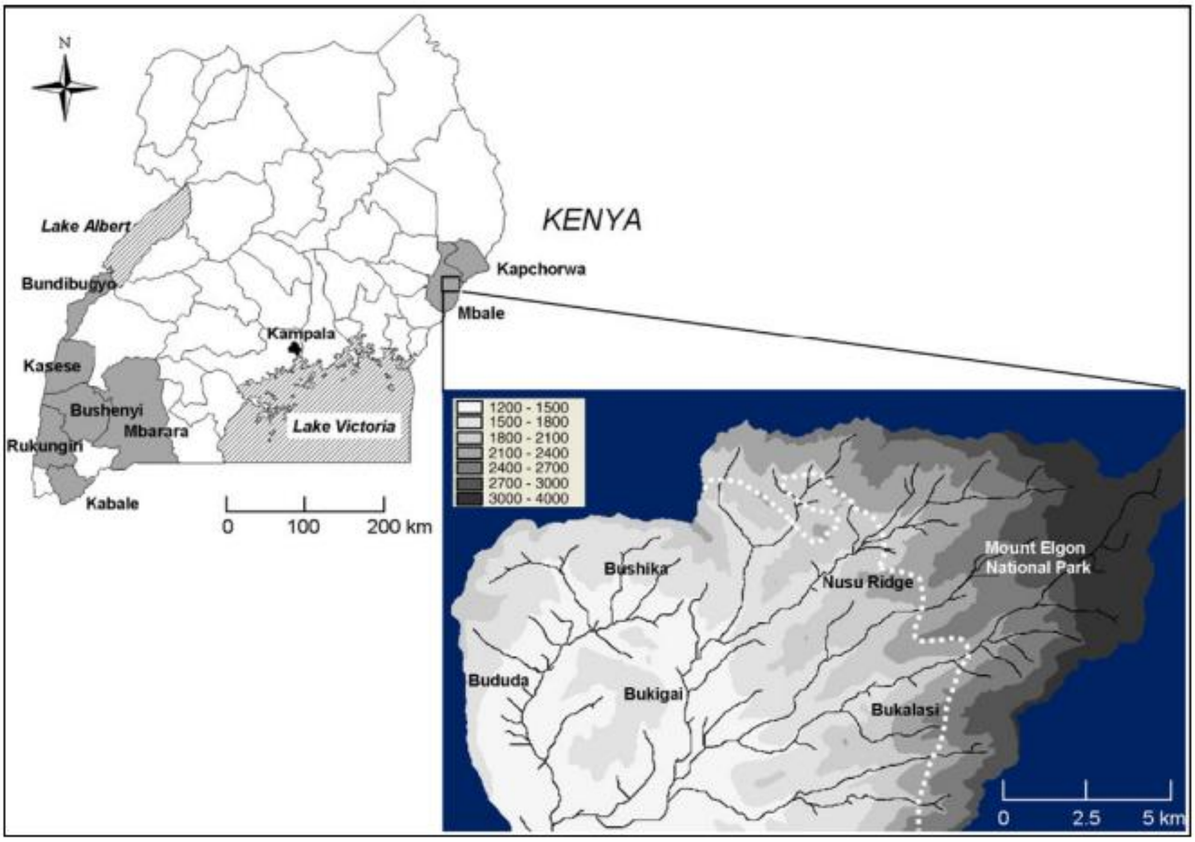
3.1.1. The case study area: STATE OF BUDUDA DISTRICT

This case study will provide the details of the site for the project, the target market description for electricity, and its environmental aspects and situation.

Location and land characteristics

Bududa district lies at the foot of the south-western slopes of the Mount Elgon. Mount Elgon is a volcano on the boundary of Eastern Kenya and Western Uganda. Bududa geographically lies within latitude 00º 58´ 45.63" N to 1º 7´ 22.07"N, and longitude 034º 16´ 18" E and 34º 32´ 6.69" E, and covers a total land area of 273.79Km^2 [99]. The geomorphology of the area within Bududa is described by volcanism and doming of the country rock [96]. The area is characterised with steep slopes and V-shaped alleys [97]. The characteristics of the soils in this area are that there is a sequence where the central carbonatite dome is covered by Rhodi andic Nitisols and surrounding areas covered by Rhodiandic Luvisols, Hapic lixic Ferralsol, and Humic andic Nitisols [96]. Water drainage from the weak slopes of Bududa meet in river Manafwa which finally drains into lake Kyoga in central Uganda. This area is within a high altitude of 1250-2850m which influences an average rainfall precipitation of above 1500 per year with two distinct wet seasons and two dry periods. It is clear that this region has a lot of water [96].

Figure 3:1: The map of Bududa location



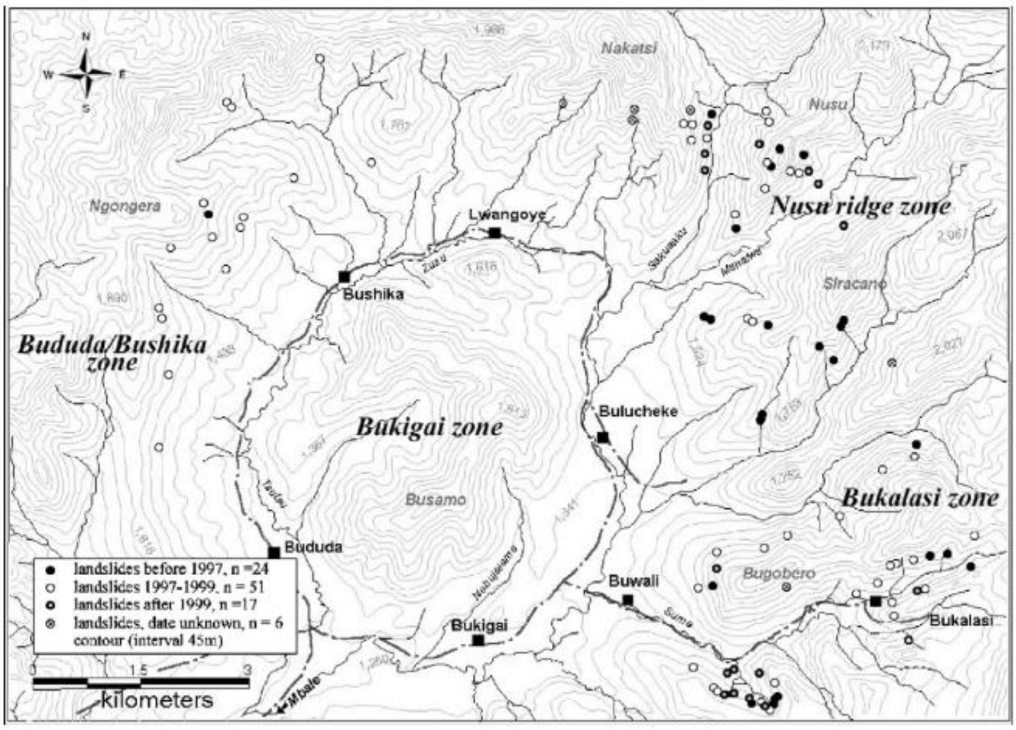
Source: [96]

Environmental aspect of Bududa

Landslides are a common occurrence in Bududa district especially during the rainy seasons. This is the region of Uganda affected most by this problem. These landslides are in form of "debris flow" which is considered one of the most dangerous of all mass wasting events. One of the most recent landslide occurrence in Bududa was in August 2013 when five villages were buried by a huge mass of soaked soil [98]. Since 1933, it is estimated that about 513 people have been killed by these landslides and many (over 10,000) have been displaced [96]. Besides undercutting of the hill slopes for construction of houses and roads, the geology (hilly slopes), land cover, weather, concentrated water flows and soil properties are considered main causes of these landslides. An interview with the residents of Bududa Identified the three main causes of landslides being steep slopes, the flow of water from underground, and existence of concavities (areas where eroded soils and water collects). The farmers/locals indicated that existence of no stones, no sticky soils and no water were characteristics of areas with little vulnerability to landslides [97].

Vegetation cover was also identified as one of the barriers to landslides. It was discovered that in this region, even steeper slopes but with vegetation cover had no landslides. Areas with similar topographic and soil properties with landslide prone areas, but were covered in vegetation had no landslide occurrences [96]. Forest cover was therefore indicated to prohibit mass movement in Bududa. Bududa has been undergoing deforestation since the 1930's, a high contribution to the causes of landslides [96]. Existence of this landslides disaster has made the people of this region even poorer due to constant loss of property and lives.

Figure 3:2: A map indicating landslide concurrencies in Bududa since 1970's



Source: [96]

Areas Bukalasi and Nusu zones of Bududa are most prone to landslides based on *image* above. These areas are characterised by steep hills and little vegetation cover.

Steep hills in Bududa are not recommended to be occupied by people because they are considered areas of high landslide hazard [96].

Land use and vegetation cover

Most of the land within the settled area is covered by subsistence crops especially Matooke (banana plantain) and Vegetables. Then 40% of the district land area is dominated by tropical forest type at the lower sides of the mountain, followed upwards the mountain by the bamboo forest type, and finally some moors and fern on the tops of the mountain. The mountainous forest reserve and bamboo forest reserve within the mountain tops and ridges are considered part of the district's natural resources and tourist attractions [99].

Economic situation of Bududa

The annual population growth rate of this area is 3.8% which is higher than Uganda's population growth rate of 3.2% [99]. Bududa district total population can be estimated to be 201,646 persons by 2015 based on estimated population of 2011 and annual growth rate of 3.8% [99]. Bududa's population density would therefore be approximately 737 persons per square Km around as of 2015 which is very high compared to the average population density of Uganda (approximately 162 persons per square Km) based on 2015 population estimates [74]. 56% of the population is below 17 years of age and 79.9% of the population is below 30years as of 2012 [99].

The main activity in Bududa is subsistence agriculture growing mainly the crops; -Bananas, coffee, beans and vegetables [97]. About 86 % of the working population are subsistence farmers. Agriculture in this hilly region of Bududa is however not as productive as it would be due to the fact that some of the most common conservation methods that normally encourage agriculture on hills, like terracing method, are discouraged from use in this area. This is because for example, terracing in Bududa promotes landslides [97] based on farmers' experience. The total number of employees of the district local government is approximately 1,052 persons, majority of which are school teachers [99]. This is very low compared to an approximate total district population of between 176,700 to 260, 648 persons as of 2011 [97, 99]. The *table* below shows the sources of livelihood within the district as of 2002 [99]. About 33% of the population live below the poverty line.

Table 3:1: Bududa household sources of livelihood

Sources of Livelihood	Household	Percent
Subsistence farming	30966	86.4
Employment	925	3.0
Business enterprise	609	1.7
Cottage industry	143	0.4
Property income	215	0.6

Family support	2509	7.0
Others	323	0.9
Total	**35840**	**100**

Source: Uganda Population and Housing Census (PHC), 2002, [99].

Most of the household settlement (88.6%) is within a radius of 5KM. The district has 32 pre-primary schools, 133 primary schools and 2 technical colleges yet, only about 2 to 3% of the primary school pupils were able to pass the final national primary leaving exam with the highest grade [99]. The education system in this area is therefore very poor.

Market viability for power and policy assessment for Bududa/Uganda

In 2014, a private company, LD Heavy Engineering (Private) Limited issued a notice to the Electricity Regulatory Authority of Uganda (ERA) of intended application for a license to generate and sell electricity from a hydropower plant of proposed capacity 5.7MW to be established on River Manafwa in Bududa District [152].

Uganda's encouragement of private investment in the renewable energy sector is emphasized by the existence of a Standard Power Purchase Agreement (SPPA) and Feed in Tariff (FiT) for grid connected Renewable Energy (RE) projects. FiT is also encouraged within the Renewable Energy Policy of Uganda [87]. This was done with an aim to reduce transaction times and also raise the level of predictability of the investment environment for RE projects [87]. FiT's are renewed periodically to reflect costs changes over time [87]. The *Table 3:2* below lists the FiT's that were submitted by the Republic of Uganda through the MEMD to the "Scaling up of Renewable Energy in low income countries Program" (SREP) [87]. The SREP terms of reference and investment plan for Uganda was endorsed in 2015 [92]. The funds within the SREP are meant to support private investors in Renewable Energy projects.

Table 3:2: Feed in Tariffs (Up to 20MW) Uganda

Technology	Eligible capacity (MW)	Tariff (US$/kWh)	Total capacity allocation (MW)	Payment period (years)
Hydro	1 - 20	0.073	180	20
Hydro	1 - 8	0.082 – 0.092	90	20
Hydro	0.5 - 1	0.109	5	20
Bagasse	-	0.081	100	20
Biomass	-	0.103	50	20

Biogas	-	0.115	50	20
Landfill gas	-	0.089	50	20
Geothermal	-	0.077	75	20
Solar PV	-	0.362	7.5	20
Wind	-	0.124	150	20

Source: [87]

Bamboo in Bududa

Bududa area, the foothills of Mount Elgon are famously known for high consumption of a traditional staple meal made out of bamboo shoots, known as "Malewa" [100]. Bamboo grows widely and wildly in this region with especially Arundinaria alpine/ Yushania Alpina (a.k.a highland bamboo) naturally growing. Based on lore from this region, Bamboo has been eaten in several forms, as both food and source for over 3000 years majorly by a tribe of people called "Bagisu" that live around the eastern region/Mount Elgon region of Uganda including Bududa region [100].

3.1.2. Estimation of Required Load for Bududa District as of 2017 and the Rated Power Output of the desired BGPP to Satisfy the Load.

Electricity demand needs and load assessment for a rural location is quite challenging. The expected electricity consumption patterns of Bududa shall be estimated based on records from previous research data of consumption patterns within Uganda.

Electricity is expected to be consumed by households, health facilities, Schools, and public institutions/local government buildings. Bududa district does not have any industries yet making it hard to estimate its future industrial energy needs. This thesis therefore excludes industrial energy supply for Bududa outside this Bamboo concept.

Estimating energy requirement per household in Bududa

This thesis considers Bududa as a normal rural location but with a new source of electricity supply, Modi et al (2006) [119] estimates each rural household to require about **15KWh per year**. This energy would be required for basic lighting services and for communication devices such as radios, and cell phone charging. On the other hand, White 2002 [120] estimates about **30KWh per household per month** in a rural location [80].

- ❖ This thesis takes the average estimates of Modi et al (2006) [119] and White 2002 [120] for rural consumption patterns. The average of both estimates is used for purposes of estimating Bududa's average household electricity consumption per month.

However, this thesis would have wished to assume that increased income in Bududa would attract urban development and therefore normal urban residential building format of Uganda as assessed by Drazu et al 2015, [101]. Most urban households rely on more than one source of energy [101]. It is expected that even with development and increased electricity access; Bududa households would still rely on Biomass but to a much lesser extent. Firewood/ wood-fuel may still be used to a very low extent majorly for traditional cooking and instead charcoal use may be more adopted for cooking purposes since people could then afford improved charcoal based cooking stoves. Literature indicates that urban households of Uganda depend on bioenergy for cooking purposes but majorly in the form of Charcoal [101].

In the urban setting, electricity is expected to be used for mainly lighting and electronics such as Mobile phones, Irons, Television, Radio, Computers, DVD players/game consoles, Electric kettles, Microwave, Refrigerator and maybe washing machines [101]. The energy consumption patterns of urban residential buildings in Kampala (Uganda) as of 2015 are indicated in *table 3:3* below: -

Table 3:3: Household energy use per month in urban residential areas of Uganda

Energy source (Percent of Households)	**High levels of consumption**	**Low levels of consumption**	**Median**
Firewood (7.6%)	450.0 kg	25.0 kg	285.0 kg
Charcoal (88.6%)	240.0 kg	10.0 kg	60.0 kg
LPG (21.5%)	50.0 kg	3.0 kg	7.5 kg
Kerosene (24.1%)	50.0 litres	0.5 litres	2.5 litres
Electricity (86.1%)	475.0 kWh	7.0 kWh	**78.3 kWh**

Source: [101]

Therefore, the urban setting of kampala would counsume 78.3kWh per household, per month. Growth of Bududa to the urban level of Uganda would take some more time. So, the gasifier system technology to be chosen for this project would have to take into account possible future adjustments to increase production of electricity, or possibility of future hybridisation of the system.

Estimation of number of households in Bududa as of 2017

Based on the 2002 population and housing census, Bududa had a total number of 27,909 households with an average household size of 4.4 persons [99] with a total population of 123,103 persons which was estimated to grow to 173,700 by 2011 [99].

- We assume a constant annual population growth rate of 3.8% from 2011 the population of 2017 is therefore estimated using the growth rate up until 2017.
- We also assume a constant average household size of Bududa to be 4.4. Using this household size and estimated district total population, we determine the total number of households in Bududa as of 2017 using the equation below.

$$\text{Estimated number of households in 2017} = \frac{\text{Estimated district total Population of 2017}}{\text{average household size}} \quad \ldots\ldots \text{(i)}$$

The Benefit Points (BP) method; Estimating the total load requirement of Bududa district

The Benefit Point system is described by Kaijuka (2007) and can be used to estimate the load requirements of a rural area [102]. Benefit points are a form of estimated load profile ratios allocated to each demand sector (households, schools, health facilities, public institutions) in a particular location and given based on needs assessment by each sector in terms of social value, willingness to pay for electricity services, future electricity consumption, and long-term sustainability. The benefit point system as used by Kaijuka (2007) was for the purpose of determining which location in Uganda had the most electrification needs based on the fact that that region had the highest number of total benefit points from all its sectors [102].

The use of benefit point values was agreed upon by the Rural Electrification Criteria Stakeholders' workshop after undertaking comparisons with studies that were done in South Africa and Namibia [102]. Suggested benefit point allocations for Uganda were given as in *table* 3:4 below.

Table 3:4: Benefit points allocation table for Uganda

Sector	Category	Comment or Qualification	Suggested formula for Uganda	Benefit point average used
	Households	Household or population per sub county	1	1
Health	Health centres	HC II	10	10
		HC III	30	30
		HC IV	70	70
		Hospital	100+ 0.6 per bed	160
Education	Schools	Primary	8 + 0.015 per pupil	12
		Post primary	9	9
		Secondary	12 + 0.025 per pupil	22
		Tertiary	16 + 0.03 per pupil	35
		Other	11	11
		Non-formal	11	11
Local government	District HQ	LC 5	30	30
	County HQ		20	20
	Sub-county HQ	LC 3	10	10
	Parish HQ		5	5

Source: IT Power Team, Indicative Rural Electrification Master Plan (IREMP) Project, Uganda [102]

With this benefit point method, the rural household is used as the basic unit, and reference point for all other institutions. The electrification and allocation of benefit points of all other institutions and facilities is therefore compared relative to the rural household unit.

Benefit points allocation for Bududa district

Data used in this section (*table 3:5*) on the state of Bududa district was retrieved from the "Bududa District Local Government Statistical Abstract" of 2012 [99].

Table 3:5: Data table for Benefit points allocation

Sector	**Category**	**Comment or Qualification**	**Total number of sub-sector in Bududa from Data** [99]	**Benefit point average used** [102]	**Total Benefit points**
	Households		49,378 (2017 estimates)	1	49,378
Health	Health centres	HC II	7 (2011)	10	70
		HC III	7 (2011)	30	210
		HC IV	0 (2011)	70	0
		Hospital	1 (2011)	160	160
Education	Schools	Primary	132 (2012)	12	1,584
		Post primary	0 (2012)	9	0
		Secondary	9 (2012)	22	198
		Tertiary (technical college)	2 (2012)	35	70
		Other (Pre-primary)	32 (2012)	11	352
		Non-formal	0 (2012)	11	0
Local government	District HQ	LC 5	1 (2012)	30	30
	County HQ		1 (2012)	20	20
	Sub-county HQ	LC 3	15 (2012)	10	150
	Parish HQ		94 (2012)	5	470
OVERALL TOTAL BENEFIT POINTS					**52,692**

- ❖ According to Benefit Point formulae, 1 household = 1 benefit point [102] and therefore is equal to 15.6 kWh electricity consumption per month.

  i.e. 1 household = 1 benefit point = 15.6 kWh per month

This method is used to calculate the expected electricity/power consumption of Bududa in MW, considering the month to contain 720 hours of electricity consumption.

i.e ((Overall total benefit points **X** each household's kWh consumption per month)/720 hours)

Therefore, this is the load in MW that must be delivered therefore by the BGPP.

Assumed Operating Hours of the BGPP

Obernberger et al (2008) [146] indicates that for an acceptable economic performance of a CHP gasification plant, the annual full load operation hours of should not be less than 6000 hours. This translates into 250 full operation days.

One year contains 8760 hours operating for 365 days a year.

This thesis assumes the BGPP will operate for an average timeframe of (6000 + 8760) = 7380 hours per year.

Estimating the Rated Power Output of the BGPP (P)

Not all electricity generated by the BGPP is delivered for final consumption. For example, some produced electricity is consumed within the system of production.

Using the equation of "The annual delivered electricity output" provided by Nouni et al. (2006) [117] below, we can estimate the P value: -

$$E_O = P(8760 * CUF)(1 - a)(1 - l). \qquad \text{(ii)}$$

Where: -

E_O →The annual delivered electricity output of a Biomass gasifier power plant (BGPP) in MWh (i.e Delivered electricity in MW*number of operation hours per year)

CUF →The Capacity Utilisation Factor

a →The fraction of generated power consumed by the auxiliaries of the BGPP

l →The fraction of electricity losses in the local distribution network. The report from the Electricity Regulatory Authority of Uganda (2011) [149] indicates that the electricity losses in distribution with the national grid were 30% as of 2010. RECP (2015) [150] reports that the Electric power transmission and distribution losses (% of output) of Uganda are 7.68%

P →rated Power output of BGPP

8760 is the total number of hours in a year. In order to use this figure, it is estimated that electricity is produced all the 365 days in a year, 24 hours each day. But since we are assuming average operation machine hours per year to be 7380hours, the expression (ii) was changed to replace figure 8760 with 7380. Below is the expression (iii) used therefore: -

E_O =P (7380*CUF) (1-a) (1-l)

$$P = \frac{EO}{(7380*CUF)\,(1-a)\,(1-l)} \quad \ldots\ldots\ldots\ldots \text{(iii)}$$

Estimations from literature to be used in calculation of P

Item	Estimation	Source
Capacity factor of biomass fired power plants (CUF)	85%	IRENA (2012) [139]
Net electrical efficiency	35%	IRENA (2012) [139] Mott MacDonald (2011) [122]
The fraction of generated power consumed by the auxiliaries of the BGPP (a)	(100%-35%)	

3.1.3. Bamboo Biomass/ Bioenergy Requirement for the Project

Bamboo Biomass gasification characteristics

This section shows the methodology used to obtain the Bamboo biomass/bioenergy gasification characteristics for Bududa.

All the species of Bamboo currently existing in Uganda can thrive in Bududa region given the soil and weather characteristics. The average characteristics of the bamboo plants shall be used within this study.

The Bamboo Gasification Info-Sheet [131] is used as literature source for the gasification characteristics of bamboo as listed in Table *3:6* below. This information is based on an actual installed bamboo gasification system /project in India.

Table 3:6: Bamboo gasification characteristics

Bamboo gasification characteristic	Quantity
Dry bamboo biomass requirement	1.0 to 1.3 Kg/kWh
Ash content in the bamboo biomass	<5%
Amount of producer gas per Kg of bamboo	2.8m^3 of producer gas /Kg of dry bamboo
Calorific value of producer gas	4.5 to 5MJ/m^3
Stoichiometric air-to-fuel ratio for biomass gasification	1:1.4 (against 1.6 required for combustion)
Composition of Producer gas	CO 20±2% H_2 18±2%

	CH_4 2±0.5% CO_2 12±2% H_2O 2% Rest is N_2
Maximum particulates of tar after cleaning and cooling	50mg/m^3
By products (Charcoal and Active charcoal)	5-15%

Source: [131]

Table 3:6 is used to find out the bamboo gasification characteristics of Bududa power plant per hour, by scaling up to Bududa's required KWh.

Estimation of required Bamboo Biomass yield and required land cover

1) Energy output of bamboo biomass

Since studies on the energy content of similar bamboo species have been carried out before, and based on the fact that this project suggests growth of a variety of the bamboo species currently in Uganda, the average energy content of Bamboo in MJ/Kg for this thesis project was estimated based on Table 2:2 and Table 2:3 by calculating the average energy contents of the different bamboo species to obtain

2) Required weight (Kg) of dry bamboo plant material per day to satisfy the required load

Using the BGPP rated power output, P, in MW (i.e MJ/s) as in section 3.1.2, and the estimated energy content of Bamboo plant in MJ/Kg, the dry bamboo consumption per second of time was calculated.

This then was used to determine how much of dry bamboo biomass (Kg) is to be consumed per hour. Knowing the number of hours for the gasification plant to operate per year, the required annual bamboo biomass in Kg and in tonnes was estimated.

3) Estimation of required land use for bamboo plantation for electricity generation

A study on natural bamboo forests and plantations found that a well-managed Bamboo plantation is known to yield on average 25t/ha/year dry matter and very productive species may yield more than 30t/ha/year [108].

This thesis assumed an expected yield of 25t/ha/year dry bamboo matter.

Knowing the required annual tonnage of bamboo biomass from section above, and using the assumed yield per acre of 25t/ha/year, the required land cover for bamboo farm to satisfy the gasification power project was estimated.

3.1.4. Estimation of Carbon intake by Bamboo (Moso bamboo)

Knowing that one hectare of bamboo (Moso species) can store up to 250tons of Carbon and also that each year, 1 hectare of bamboo (Moso species) absorbs 5.1 tons of carbon [145], the annual carbon storage and carbon uptake of the bamboo plantation specifically for the gasification plant was estimated using results from section above.

3.1.5. Technical Installation Design Methodology

The design and selection of systems for the gasification power plant applicable to this thesis was done based on several literature sources and comparisons of current and future technologies. Here are the literature sources that were used to conclude on the technical specifics: -

	Section	**Literature sources**
1	Supply chain Management, Biomass harvesting, collection and transport	[115] and [126]
2	Pre-treatment of Biomass involving particle size reduction (Palletisation) and drying	[116], [121], [126], [138], [139], [144]
3	Selection of gasification technology	[52], [115], [122], [139], [140]
4	Gas cleaning;	L. Yang et al. [118]
5	Electricity generation system including the Internal Combustion Engine (ICE) and the Generator	[126]
6	Designing the flow diagram for the technical installation	Nouni et al., 2007 [117]

3.2. ECONOMIC ANALYSIS METHODOLOGY

The economic analysis is used to determine production costs and all its major components. It includes capital costs, operation & maintenance costs and expected revenues from the project. These costs and revenues can be used to determine the Return on Investment [138].

3.2.1. Capital Cost Methodology

Capital costs are normally affected by factors such as site/location, feedstock type, technology type and capacity rating [122]. The capital cost of a biomass gasifier power plant comprises majorly the costs of gasifier, engine–generator set, civil works, and distribution network [117]. Shah et al (2016) [138] shows that the total Capital Investment is the sum of Direct Fixed Capital (DFC), Working capital and Start-Up capital. DFC is the total cost of designing, constructing, and installing a plant. Working capital includes tied up funds required to operate a plant such as Investment in raw materials, consumables, labour and utilities. Start-Up costs include one-time investments to prepare a new plant for operation and validation.

From the Biomass CHP catalogue of USA (2007), the total capital cost of a biomass gasification power generation system CHP with maximum thermal output was estimated to be **$2,333 per kW**. These capital costs included prep-yard, gasifier and supporting systems, and the prime movers (reciprocating engine, gas turbine, and steam turbine generators) with its supporting systems [144].

In India as of 2010, literature shows that typically, the cost of a biomass gasifier based technology for electricity generation ranges between Rs40 to 45 million/MWe (USD 619,732.46/MWe to USD 697,202.31/MWe), [116].

According to Mott MacDonald's estimates (2011) [122], capital costs of woodchip gasification plants are estimated to be £4300 per kW which is approximately **$5620.29 per kW** (*appendix 3*). This Capital cost estimates here were based on the few pre and early commercial stage projects in the UK. Mott MacDonald estimated that Fixed Bed capital costs is likely to fall as proven and reliable models become established but it was difficult to apply a time frame to these developments. Unlike Fluidized Bed gasifiers which normally have lower capital costs, Fixed Bed gasifiers operate with low scale failing to utilize the economies of scale advantages [122].

<u>Capital cost assumption and estimation methodology used:</u>

The two gasification projects that were previously installed in Uganda were running with capital costs of $2,087 and $2,890 per kW respectively. These capital costs included Feasibility study, building, gasifier, gas engine, shipping, customs duty, insurance, clearance, fuel wood processor, wood processing shed, installation and commissioning, additional electricity controls, initial training and grid extension.

For this project, it was assumed the capital cost would be the average of the above two costs which is $2488.5 per kW

Knowing the fact that the technologies have decreased cost with time within the last 10 years, this must affect that cost downwards. But also, considering the escalation rate and change in money value with time, i.e. the money value of Uganda has gone down against the dollar in the last 10years, this means that most of the capital costs within Uganda would stand at higher value than they did 10 years ago. So, these two factors could maintain the capital cost at that average.

3.2.2. Operation and Maintenance Cost Methodology

Feedstock cost estimates

There is no current data on costs of mature bamboo stem in Uganda. However, in the neighbouring Kenya, a mature stem/culm of bamboo (4 years) costs KSH40 which is equivalent to UGX 1387 and USD 0.385 [143]. The costs of Bamboo in Kenya were used to estimate the costs charged in Uganda.

Kigomo (2007) [143], indicates the number of expected bamboo plants and culms per hectare. Using this estimate and the current costs of bamboo culms in East Africa, the bamboo feedstock costs are estimated.

Other Operation and Maintenance costs

These are costs required to run the plant. Mott MacDonald's estimates (2011) [122] indicates that O&M costs can be categorised into Fixed Operation and Maintenance (FOM) costs and Variable operation and maintenance (VOM) costs.

Shah et al. (2016) [138] shows that generally, parameters associated with operating cost can be divided into three main categories: (1) direct costs; (2) indirect costs and (3) general costs.

For the calculation of operating cost parameters for this thesis, an excel sheet for calculation was created based on the method for estimation of O&M costs by Shah et al. 2016) [138] as in table 3:7 below:

Table 3:7: Operating cost parameters and calculation procedure

Operating Cost Parameter	Calculation Procedure

Direct costs	
Raw materials	Quantity in input stream X material price/unit
Consumables (catalysts, adsorbents)	Quantity X material price/unit
Effluent disposal cost	Quantity X disposal cost/unit
Utilities (fuel, electricity, steam, water, cooling agents)	Quantity X unit cost
Operating labour	Labour hours X wage rate
Operating supervision	0.2 X operating labour cost
Quality control	0.2 X operating labour cost
Maintenance labour	0.027 X DFC
Maintenance material	0.018 X DFC
Maintenance supplies	0.0075 X DFC
Indirect cost	
➢ **Fixed costs**	
Depreciation	Expression (below –*number it*)
Property taxes	0.02 X DFC
Insurance	0.01 X DFC
➢ **Plant overheads**	
Fringe benefits	0.22 X (operating labour + supervision)
Overhead	0.50 X (operating labour + supervision)
General cost	
Administrative	0.045 X production cost
Marketing	0.135 X production cost
Financing (interest)	Annual interest
Research and Development	0.0575 X production cost
TOTAL O&M COST	**Sum of all the above**

Source: Shah et al. 2016) [138]

The production cost = is defined as including raw materials and labour

=Direct operating costs

<u>Direct costs</u> [138]

Raw materials: - This is usually the main contributor to the total operating cost of the plant. For most chemical industries, raw materials accounts for 80-90 % of the total operating cost.

Consumables: - These are process specific and include solvents, acids, bases, inert materials, inhibitors, additives, catalysts and adsorbents. The cost of consumables is usually less than 3% of the total operating cost [138].

Effluent disposal: - If effluent is treated, this may affect the operating cost [138]. Instead of effluent disposal, there may be Ash disposal costs. IRENA (2012), [139] estimates ash disposal costs of approximately USD132/tonne. However, ash disposal and other effluent disposal costs vary significantly by region depending also on quantities of ash or whether there is a local market for ash or not [139].

Utilities: - These are required to run the process plant and may include fuel and electricity, heating and cooling agents, process water and gases (air, oxygen etc.) [138].

Labour requirements: - this is requirement for the operation of different process equipment. This ranges between 0.01 to 4 labour hours per equipment operation hour. Operator salaries vary by region and experience level. Supervision and management costs are typically taken as 25% of operating labour costs. The actual level of supervision that is required depends on the extent of the plant or site [138].

The operating labour salaries of Uganda were estimated using the net average salary details of Uganda.

Maintenance costs: - Include replacing, repairing parts, equipment, and costs of labour and supervision needed to carry out the maintenance work. Maintenance cost is estimated to be between 3 to 6% of installation and equipment investment. Plants with more moving equipment or more solids handling usually require higher maintenance [138].

Indirect costs

Depreciation charges: - This is the most common type of tax allowance used by governments as an incentive for investment. For TEA, depreciation determines the contribution of equipment cost on the operating cost. There are several methods for determining this cost, however, Shah et al. (2016) [138] indicates that the below expression (iv) is a commonly used expression probably due to its simplicity [138].

$$\text{Annual depreciation} = \frac{(\text{Purchase cost} - \text{Salvage Value})}{\text{Service life}} \quad \text{.........................} \quad \text{(iv)}$$

For chemical plants such as gasification, salvage value is taken as zero since the plant usually continues to operate for many years beyond the end of depreciation life [138]. So, the expression becomes: -

$$\text{Annual depreciation} = \frac{\text{Purchase cost}}{\text{Service life}} \qquad \text{………………… (v)}$$

Insurance costs: - All plants require this to cover third party liability as well as potential plant damage. This contributes typically between 1-2% of the total of "equipment purchase, installation, yard preparation and auxiliary factors" share of capital costs per year [138].

Land (Property taxes): - Most projects assume land is rented rather than purchased. In cases where the land is bought, the coast is added to fixed capital recovered at the end of the project life. Rented land is also typically estimated to be about 1-2% of the total of "equipment purchase, installation, yard preparation and auxiliary factors" share of capital costs investment [138].

Plant overheads and Fringe benefits: - overhead costs are the costs of providing benefits and training to employees. These include non-salary costs like health insurance, training courses and benefits, such as subscriptions and professional society memberships. Direct salary overhead typically varies between 40% and 60% of labor plus supervision costs [138].

General costs

General costs are incurred for the management of a plant, such as administrative, marketing, financing and research and development costs. Administrative cost is estimated as 3 to 6% of the production cost, marketing cost varies between 5-22% of the production cost, and research and development cost is estimated as 3-8% of the production cost [138].

3.2.3. Levelized Cost of Electricity Methodology (LCOE)

The LCOE of renewable energy technologies is a widely used measure by which renewable energy technologies can be evaluated for modelling or policy development purposes. The LCOE of renewable energy technologies varies by technology, country and project, based on the renewable energy resource, capital and operating costs and the efficiency/performance of the technology [139]. This study intends to understand whether the LCOE from this project is competitive based on current Ugandan costs of grid electricity [151] as seen in *table 3:8* below, and also with comparison to the Uganda Feed in Tariffs.

Table 3:8: 2017 Electricity charges of Uganda

	Cost (UGX/kWh)	**Cost (USD/kWh) Conversion of 29/07/2017**
Domestic consumers	687.1	0.19
Commercial consumers	620.9	0.17

Medium industrial consumers	569.7	0.16
Large industries	370.2	0.10
Extra-large industries	366.9	0.10
Street lighting	671.2	0.19

Source: [151]

IRENA (2012) [139] uses an approach in the analysis of LCE presented here, based on a discounted cash flow (DCF) analysis. This method based on discounting financial flows (annual, quarterly or monthly) to a common basis, takes into consideration the time value of money. Here, the weighted average cost of capital (WACC), also often referred to as the discount rate, is an important part of the information required to evaluate biomass power generation projects and has an important impact on the LCOE. The formula (vi) used by IRENA (2012) [139] below shall also be used for purposes of this thesis: -

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \text{.................. (vi)}$$

Where:

LCOE = the average lifetime Levelized Cost of Electricity generation

I_t = investment (capital cost) expenditures in year t

M_t = O&M expenditures in year t

F_t = Fuel (feedstock) expenditures in year t

E_t = Electricity generation in year t

r = discount rate

n = life of the system

The assumptions necessary for the calculation of the LCOE cost above are listed in *table 3:9* below: -

Table 3:9: Needed assumptions for LCOE calculation

Item	**Assumption**	**Source**
Discount rate	10%	IRENA (2012) [139]
Economic life of the gasification plant	20 years	IRENA (2012) [139]
Equipment and capital costs		Section 3.5.3.1

O&M costs		Section 3.5.3.2
Feedstock costs		Section 3:3:2
Capacity factor of biomass fired power plants	85%	IRENA (2012) [139]
Net electrical efficiency	35%	IRENA (2012) [139] Mott MacDonald (2011) [122]
Ash disposal	1%	IRENA (2012) [139]

With the above details, the LCOE for the expected Load to be delivered by the BGPP was therefore estimated.

3.2.4. Investment Analysis

For the investment analysis, we assumed: -

- An initial equity investment of USD 2,836,890 (i.e. the capital cost).
- The electricity from this project will be sold directly to consumers at the same price as the current national grid's electricity charges for domestic consumption (0.19USD/kWh).

Then, using excel, we estimated: -

- the Net Present Value (NPV) after the project lifetime; which is the summation of all discounted cash flows
- the Internal Rate of Return (IRR) calculated when NPV=0
- the Payback period of the investment
- the discounted Payback period of the investment

These four parameters were further used to investigate whether the BGPP is worth an investment.

If the NPV is greater than zero, and the IRR is greater than the discount rate, the BGPP would be economically feasible.

CHAPTER FOUR: RESULTS AND DISCUSSION

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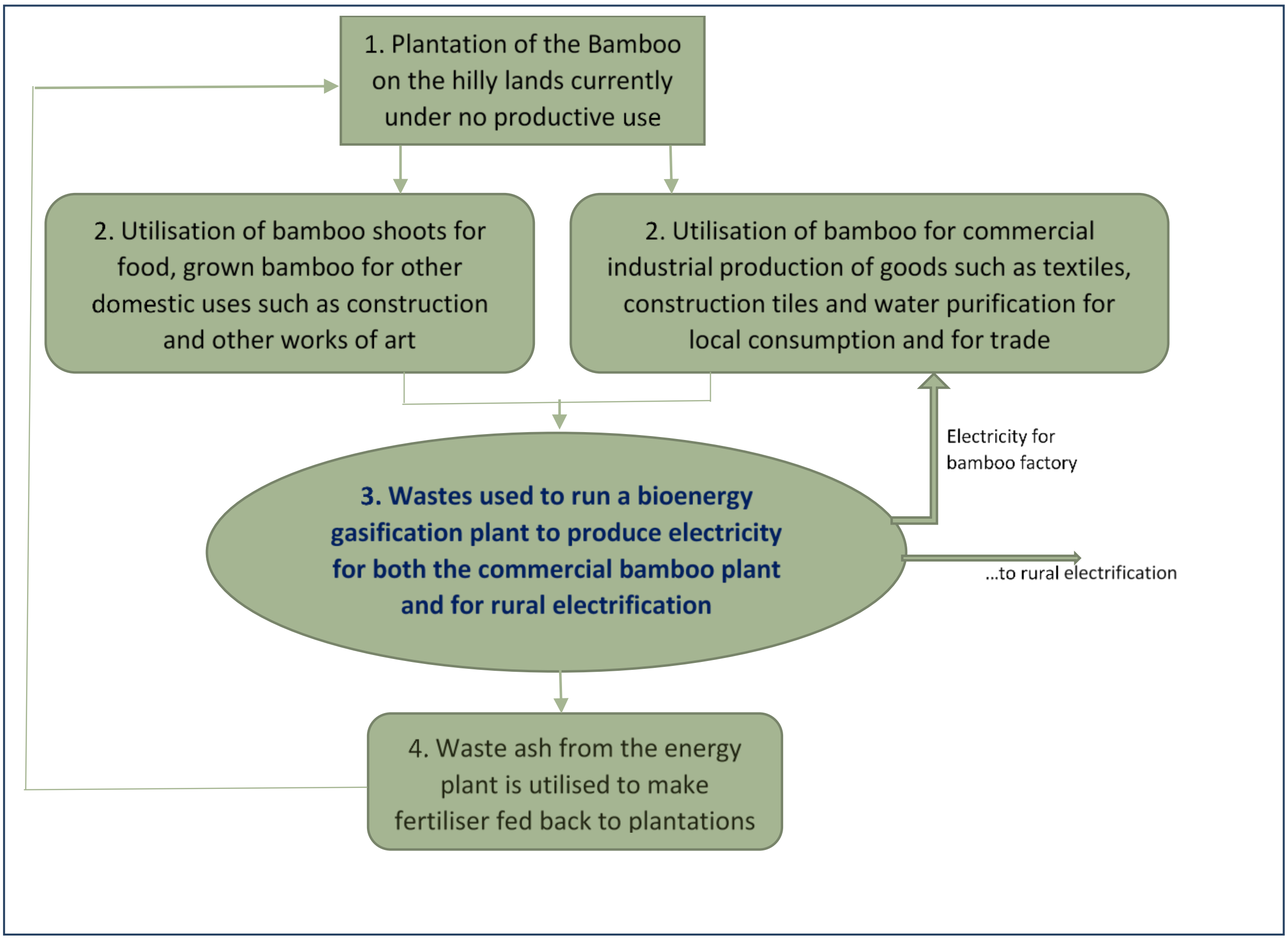
4.0. INTRODUCTION

This chapter uses mainly secondary data to suggest a concept for rural economic growth within which the bamboo based BGPP is built. In addition, data assessment is utilised to estimate the Load requirements of Bududa district and load consumption pattern, the output capacity of the BGPP, the amount of bamboo biomass required as feed for the BGPP along with estimated land cover for the biomass, the potential for carbon storage and absorption by the bamboo plantations of the BGPP and the bamboo gasification characteristics. This chapter also concludes on the specific technical installation requirements that will be needed for the BGPP along with estimations of the required costs for the BGPP and the investment analysis.

4.1. INNOVATION OF A BAMBOO BASED SUSTAIBABLE ECONOMIC MODEL FOR BUDUDA

In order to ensure affordability of the energy being produced by this region, a sustainable model for income generation within which the energy plant is apart is suggested below. This model assures a cyclic sustainable, zero waste concept within which there is plantation of trees (bamboo grassland trees), utilisation of these plants for several uses, wastes from processing and extra farm land plant materials shall all be used to produce electricity through the gasification plant, and then the wastes from the gasification plant (mostly ash) would be used to make fertiliser fed back into the plantations and other agricultural fields. *Figure 4:1* below illustrates this concept model. This concept model was built based on studies of several literature in which the bamboo plant is being utilised for several economic purposes in communities especially in Asia.

Figure 4:1: Illustration of the innovated concept model



Expected sustainable impact of this concept

i) Rural electrification

ii) Source of food from the bamboo plantations since bamboo shoots are staple food to the locals

iii) Holding back onto the soil erosion on the hills and thus acting as means to avoid landslides in the land slide prone area of Bududa;

iv) Making use of the hilly areas that have been deemed unfit for peoples' settlement and agriculture

v) It would create enterprise at local level and improve the livelihoods of the while district community

vi) There would be creation of job opportunities and therefore income for the local people

vii) Improved infrastructure and indirect benefits to schools and hospitals as there would be access to furniture

viii) Attraction of other businesses and commercial services into the area that would require energy to run

ix) Contribution to climate change by production of oxygen and increment of the carbon sink

This model generally fits right within the 2030 Sustainable Development Goals (SDGs). It has high potential to directly contribute substantially towards achievement of 14 out of the 17 SDGs namely: - No poverty, Zero hunger, Good health and wellbeing, Quality education, Gender equality, Clean water and sanitation, Affordable and clean energy, Decent work and Economic growth, Industry Innovation and Infrastructure, Reduced inequalities, Sustainable cities and communities, Responsible consumption and production, Climate Action, and Life on land.

This concept may also contribute indirectly to the other 3 SDGs i.e. Life in water, Peace Justice & Strong Institutions, and Partnerships for the Goals [95].

This concept therefore could hold very strong ability to completely transform Bududa district or any other locations with similar characteristics and challenges and therefore make people able to afford electricity.

Estimated economic benefits of this Bamboo community project

This concept is expected to increase the overall income of Bududa district residents. The term *Income* in this paper shall be termed as "the value added of labour and capital (including land)" as was defined by the 2007 Poverty Environment Network (PEN) Technical guidelines [112].

The NL Agency of Netherlands reports that about 1000 culms are available per hectare per year. It also reports that when bamboo is combined with processing, producers may earn 12 dollars per culm [108]. This could sum it up to about 12,000 dollars per hectare per year when selling processed culms. This could be a potential source of income for the rural communities especially in supply of housing materials [108].

4.2. TECHNICAL ANALYSIS

This section explores the key parameters and technicalities involved in the BGPP project installation.

4.2.1. Load Estimation for Bududa Rural District as of 2017

Estimation of household and residential energy consumption

Based on the 2002 population and housing census, Bududa had a total number of 27,909 households with an average household size of 4.4 persons [99] with a total population of 123,103 persons which was estimated to grow to 173,700 by 2011 [99].

- Assuming a constant annual population growth rate of 3.8% from 2011 and a constant average household size of 4.4 persons, the population of 2017 would be approximately **217,262** persons and therefore the number of households would be approximately **49,378**. See calculations of population estimates from 2011 to 2015 in *table 4:1* below and following equation: -

Table 4:1: Calculation to estimate the population of Bududa district

Year	Population estimate (number of persons)	Estimation of population for the following year
2011	173,700	(173,700 *(3.8/100)) + 173,700
2012	180,300.6	(180,300.6 *(3.8/100)) + 180,300.6
2013	187,152.0228	(187,152.0228*(3.8/100)) + 187,152.0228
2014	194,263.7997	(194,263.7997*(3.8/100)) + 194,263.7997
2015	201,645.8241	(201,645.8241*(3.8/100)) + 201,645.8241
2016	209,308.3654	(209,308.3654*(3.8/100)) + 209,308.3654
2017	217,262.0833	(217,262.0833*(3.8/100)) + 217,262.0833

<u>Estimated number of Households in Bududa by 2017</u>

$$\text{Estimated number of households in 2017} = \frac{\text{Estimated district total Population of 2017}}{\text{average household size}}$$

$$= \frac{217{,}262.0833}{4.4}$$

$$\mathbf{=49{,}377.7462}$$

Estimating energy requirement per household in Bududa

Instead, considering Bududa as a normal rural location but with a new source of electricity supply, Modi et al (2006) [119] estimates each rural household to require about 15KWh per year. This would translate into 1.25KWh per month. On the other hand, White 2002 [120] estimates about 30KWh per household per month in a rural location [80].

This thesis will therefore assume each Bududa district household would require an average of **15.6KWh per month** (average between Modi et al. (2006) and White (2002)).

Estimation of Bududa district total energy consumption based on Benefit Point Method (BPM)

According to Benefit Point formulae, 1 household = 1 benefit point [102] and therefore is equal to 15.6 kWh electricity consumption per month.

Table 4:2: Calculating electricity demand per month for Bududa (kWh) with BPM

Sector	Category	Total Benefit points	Electricity demand per month (kWh)	Percentage sectoral share
Households	Households	49,378	770,296.8	93.71%
Health	Health centres	70	1,092	0.84%
		210	3,276	
		0	0	
		160	2,496	
Education	Schools	1,584	24,710.4	4.18%
		0	0	
		198	3,088.8	
		70	1,092	
		352	5,491.2	
		0	0	
Local government	District HQ	30	468	1.27%
	County HQ	20	312	
	Sub-county HQ	150	2,340	
	Parish HQ	470	7,332	
OVERALL TOTAL BENEFIT POINTS		**52,692**	**821,995.2**	**100%**

The expected electricity/power consumption of Bududa is therefore 821,995.2 kWh per month. The estimated electricity Load requirement of the district is therefore expected to be (821995.2 kWh /720h) =1,141.66kW or **1.14MW.**

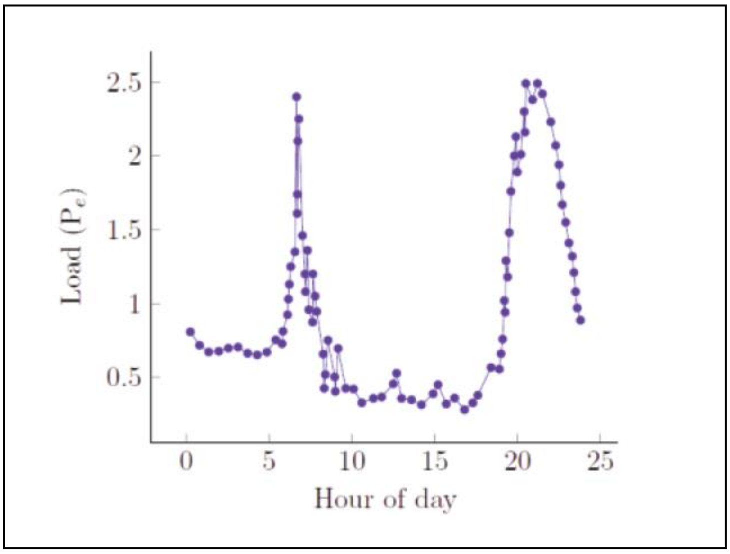
1.14MW of electricity should therefore be delivered for consumption by the district.

Expected consumption patterns of this electricity in Bududa

Prinsloo et al. (2016) [137] describes the graph in *figure 4:2* below as the common hourly based rural load profile in Uganda. This load profile would typically characterise Bududa district since the household sector is the majority electricity consuming sector (93.71% of the total district consumption from Table 4.2 above).

This graph in *figure 4:2* below indicates that there is expected to be an energy peak in the morning with a slightly higher energy peak in the evenings. This is characteristic of typical domestic consumption and where power consumers actively use power when at home in the morning hours to prepare for the day and in the late evening/night hours mainly for lighting and a few electrical gadgets [137].

Figure 4:2: Expected average household load profile in Bududa



Source: [137]

As of 2002, Bududa had two agro-processing plants [99]. In periods of low household power consumption (during the day time hours), either the agro processing industry or if the national grid is extended to this village, would be fed with the un-utilised power. If the industrial sector cannot consume the extra power and there is no grid in the area to supply it, there would be halting the gasification process and therefore halting electricity production.

Note: See *appendix 1* for data on details of potential power consuming sectors of Bududa district as of 2002.

Estimating the Rated Power Output of the BGPP (P)

Using equation (iii) in section 3.1.2 below

$$P = \frac{EO}{(7380*CUF)\ (1-a)\ (1-l)}$$

$$P = \frac{(1.14MW*7380h)}{6273h*0.35*0.925}$$

$$P = 4.1426MW$$

Summary of results from this section 4:2:1

Parameter	Result
Population of Bududa as of 2017	217,262
Average Household size	4.4
Number of Households in Bududa as of 2017	49,378
Average power consumption per household of Bududa	15.6KWh per month
Power consumption of Bududa district	821,995.2 kWh per month
Number of district consumption hours per month	720 hours (24hours X 30 days)
Electricity Load requirement of the district (Electricity to be delivered by the BGPP), Eo	1.14MW
Rated Power output of the BGPP, P	4.1426MW

4.2.2. Bamboo Biomass/ Bioenergy Characteristics for the Bududa Project

Estimation of Bamboo gasification characteristics for the Bududa power project

Table 4:3 below is an adjustment of table 3:6 on "bamboo gasification characteristics" [131] in section 3:2:3 of methodology scaled up to estimate the bamboo characteristics for 4142.6kWh power output capacity of the BGPP.

Table 4:3: Characteristics of gasification of Bamboo for Bududa (4142.6kWh)

Bamboo gasification characteristic	**Quantity**	For 4.1426MW **in one hour** (4142.6kW x 1h) = 4142.6kWh
Dry bamboo biomass requirement	1.0 to 1.3 Kg/kWh	4142.6Kg to 5385.38Kg
Ash content in the bamboo biomass	<5%	<5%
Amount of producer gas	2.8m^3 of producer gas per Kg of dry bamboo	2,279.34m^3

Calorific value of producer gas	4.5 to 5MJ/m^3	4.5 to 5MJ/m^3
Stoichiometric air-to-fuel ratio for biomass gasification	1:1.4 (against 1.6 required for combustion)	1:1.4
Composition of Producer gas	CO 20±2% H_2 18±2% CH_4 2±0.5% CO_2 12±2% H_2O 2% Rest is N_2	CO 20±2% H_2 18±2% CH_4 2±0.5% CO_2 12±2% H_2O 2% Rest is N_2
Maximum particulates of tar after cleaning and cooling	50mg/m^3	113,967m^3
By products (Charcoal and Active charcoal)	5-15%	5-15%

Estimation of required bamboo biomass yield and required land cover

1) Energy output of bamboo biomass

The average energy content of Bamboo is estimated to be 18.3 MJ/kg [5, 10]. Also, taking the average calorific values of different bamboo species Table 2:2 and Table 2:3 we obtain 18.32 MJ/kg as shown below: -

(19.1 + 19.6 + 15.85 + 18.96 + 18.61 + 17.92)/6 = 18.32 MJ/kg

The average energy content of dry bamboo is therefore approximately 18.32 MJ/kg……. (a)

2) Required weight (tonnes/t) of dry bamboo plant material to satisfy BGPP output capacity of 4.1426MW

- The BGPP capacity is 4.1426MW.
- Therefore, Bududa requires 4.1426MJ/s of power …………………………….. (b)
- Comparing (a) and (b): -

$$= \frac{4.1426\text{MJ/s}}{18.32\text{MJ/Kg}}$$

- 0.2261Kg of dry bamboo are consumed by BGPP per second
- 0.2261 X 3600 = 814.05
- 814.05 Kg of dry bamboo are required per hour

The yearly operation hours of the BGPP are 7380 hours (based on section 3.1.2).

- 7380hours X 814.05 Kg = 6,007,689 Kg = 6,007.689tonnes per year
- Therefore, **6,007.689t** of dry bamboo are required to run the BGPP annually.

Required land use for bamboo plantation for electricity generation

From section above, 6,007.689t of dry bamboo biomass are required per year for the BGPP. A study on natural bamboo forests and plantations found that a well-managed Bamboo plantation is known to yield on average 25t/ha/year dry matter and very productive species may yield more than 30t/ha/year [108].

Assuming an average yield of 25t/ha per year, the land required would be

- $\frac{6{,}007.689t}{25t/ha}$ = 240.308ha for operations per year

This translates into a minimum of 2.4Km^2 of land.

Given the land area of Bududa district is 273.79Km^2, only about 0.88% of the total land area of Bududa district is required for Bamboo biomass growing in order to satisfy the BGPP.

In conclusion, the land requirements for bamboo plantation are very small.

Estimation of carbon intake by bamboo (reference to Moso species)

1 hectare of bamboo can store up to 250t of Carbon. Each year, 1 hectare of bamboo absorbs 5.1 t of carbon [145]. Therefore, there would be potential of

- 60,077t of carbon stored each year
- 1,225.57t of carbon absorbed per year

Summary of results from this section 4:2:2

Parameter		Result
1	Average energy content of dry bamboo	18.32 MJ/kg
2	Weight of dry bamboo biomass required per year	6,007.689 t
3	Annual land cover of bamboo	240.308 ha
4	Carbon storage per year	60,077 t
5	Carbon absorbed per year	1,225.57 t

4.2.3. Biomass Feedstock Market Arrangement

Unlike other renewable energy technologies, bioenergy technologies require a feedstock that must be produced, collected, transported and stored. The economics therefore of a gasification plant depend a lot on the availability of secure, long term supply of biomass feedstock at a competitive cost [131].

The bamboo feedstock plantation can be arranged in form of a community based farmers' association similar to the rice growing community based association in Dano watershed of Burkina Faso. In this arrangement, a large chunk of land owned probably by the government is let out to the farmers' association. The association sections it into small plots such as 1-acre plots each managed by one farmer and member of the association. Through this association, it is easier to offer training to the farmers, share challenges and solutions and obtain any form of any other support by the association such as financial support to the bamboo farmers. Each small plot can also be better managed to ensure maximum biomass productivity of the plantation. In addition, through this association, it is easier to collectively discuss with the management of the BGPP for prices on the bamboo biomass as the feedstock market changes with time.

4.2.4. Technical Installation Description and Analysis

Because of the current economy of Uganda, the gasification system to be utilised should have maximum possible efficiency at low costs. Therefore, a more developed technology that satisfies output capacity of 4.1426MW and is less costly would be preferred. There are 5 stages that will be required for the successful bamboo gasification CHP plant: -

1) The supply chain management

The supply chain involving harvesting, collecting, and transportation of bamboo biomass will maximally involve the local community. The harvesting and collection cost will be determined by the owner of the gasification plant [115]. The costs of biomass can be fair enough to benefit both the local community distributers and also the gasification plant.

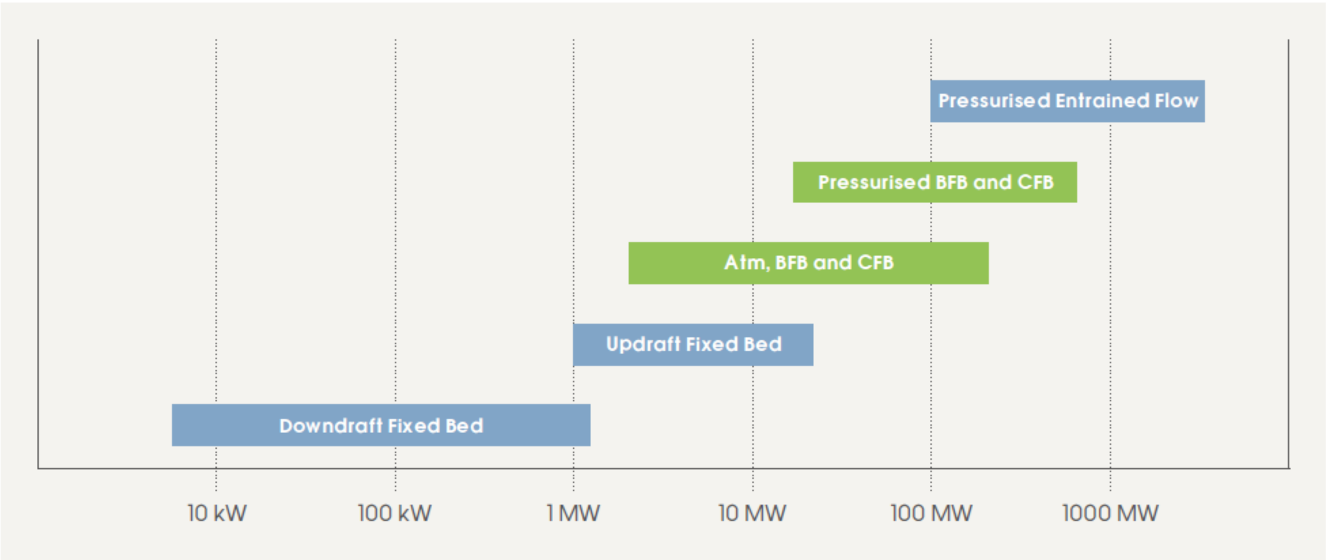
- Biomass harvesting can be done with modified agricultural equipment [126]. However, for purposes of cutting costs of buying such equipment, manual labour is preferable to be utilised in this case. This is a common less expensive practice by tree traders in Uganda.

- The level of transportation depends greatly on the developmental level of the country [126]. For Uganda, to ensure low costs, collection and transportation after harvesting of feedstock in the plantation will be done by a truck for longer distances or manually for short distances. A transport distance of 50 – 80 Km is considered economically feasible [126].

2) Selection of gasification Technology

Different types of gasifiers are suited for different size ranges. Fixed bed downdraft gasifiers do not scale well above 1MW due to their difficulty in maintaining uniform reaction conditions. Fixed bed updraft gasifiers have fewer restrictions on their scale of operation while fluidised Bed gasifiers and entrained flow gasifiers provide large scale solutions [139]. From *figure 4:3* below, IRENA (2012) [139] report indicates the preferred choice of gasifier size based on the required electrical capacity to be produced [139, 140]. This Image indicates which gasifier capacities are available and which type is most suitable for which capacity

Figure 4:3: Preferred gasifier size by type



Source: RENSFELT, 2005.

The choice for gasification system to be used will therefore be the fixed bed, Up-draft gasifier. Much as downdraft gasifiers produce much less tar than updraft gasifiers [52], they cannot facilitate higher power capacities [139]. The Up-draft gasifier has a higher electricity generation capacity [139]. We cannot use fluidised bed gasifier because Fluidized bed gasifiers are generally used for applications of larger capacities compared to fixed bed gasifiers, typically above 2.5 MW [52, 122]. Also, Fluidised Bed gasification is a relatively recent development and its application has mostly remained limited to developed countries so far [52].

3) Pre-treatment of biomass

Besides the properties of the biomass feed, biomass pre-treatment affects the performance of a gasifier [116]. Pre-treatment of the biomass gives a homogeneous high Calorific Value feedstock [121].

- Particle size reduction (palletisation)

The chipping /pelletizing machine would be used at the start of the process before drying. Since about 224.02 Kg would be required per hour, a pelletizer machine with capacity of 224.02Kg/hour would be required. (See *appendix 2* for sample of Swedish suppliers for small scale pelletizers [126, 138]. For this particular thesis, 6-100mm size is required for operation particularly for the up-draft gasifier [139] according to *figure 4:4* below: -

Figure 4:4: Biomass power generation technologies and feedstock requirements

Biomass conversion technology	Commonly used fuel types	Particle size requirements	Moisture content requirements (wet basis)	Average capacity range
Stoker grate boilers	Sawdust, non-stringy bark, shavings, end cuts, chips, hog fuel, bagasse, rice husks and other agricultural residues	6 - 50 mm	10 - 50%	4 to 300 MW many in 20 to 50 MW range
Fluidised bed combustor (BFB or CFB)	Bagasse, low alkali content fuels, mostly wood residues with high moisture content, other. No flour or stringy materials	< 50 mm	< 60%	Up to 300 MW (Many at 20 to 25 MW)
Co-firing: pulverised coal boiler	Sawdust, non-stringy bark, shavings, flour, sander dust	< 6 mm	< 25%	Up to 1500 MW
Co-firing: stokers, fluidised bed	Sawdust, non-stringy bark, shavings, flour, hog fuel, bagasse	< 72 mm	10 - 50%	Up to 300 MW
Fixed bed (updraft) gasifier	Chipped wood or hog fuel, rice hulls, dried sewage sludge	6 - 100 mm	< 20%	5 to 90 MW_{th}, + up to 12 MW_e
Downdraft, moving bed gasifier	Wood chips, pellets, wood scrapes, nut shells	< 50 mm	< 15%	~ 25 - 100 kW
Circulating fluidised bed, dual vessel, gasifier	Most wood and chipped agricultural residues but no flour or stringy materials	6 - 50 mm	15 - 50%	~ 5 - 10 MW
Anerobic digesters.	Animal manures & bedding, food processing residues, MSW, other industry organic residues	NA	65% to 99.9% liquid depending on type (i.e. from 0.1 to 35% solids)	

Source: [139, 144]

- Drying (and storage system) reduction of the moisture content of the biomass shall be performed before the gasifier. The exhaust gases from the ICE shall be used as they are a very efficient way to dry biomass. Heat from exhaust has capacity to dry the biomass from 70% to 10% moisture content. Rotary kilns are most commonly used biomass dryers. [126]. For this thesis, using up-draft gasifier, less than 20% moisture content is required [139].

4) Gas cleaning [115]

Since the internal combustion engine can only accept very limited concentration contaminants in the syngas, it imposes mandatory cleaning of the product gas by removing the contaminants to a certain minimum level. Gas cleaning would therefore be necessary to remove especially particulate matter (such as soot and ash) and also remove Tar. Bamboo biomass has very low sulphur content so it would not be necessary to include the sulphur removal methods. CaO is preferable for improvement of the combustible gas components of syngas and reduce CO_2 production.

For Tar removal, physical gas cleaning method will be preferred because it requires low temperatures. Also, catalytic method would be less preferred because of requiring high temperatures and also to avoid a possibility of catalytic poisoning as described by L. Yang et al. [118]

5) Electricity generation system (Internal Combustion Engine and Generator)

The Gas Engine (Internal combustion engine, ICE) was chosen over all other energy conversion devices especially because it’s one of the cheapest technologies and because of other more advantageous reasons as indicated in *Table 4:4* below [126]: -

Table 4:4: Advantages and disadvantages of various energy conversion devices for syngas from biomass gasification

Energy Conversion device	Net electrical efficiency of gasification plant	Main advantages	Main disadvantages
Steam turbine	10 – 20%	-Turbine components isolated from combustion products -Long maintenance intervals, high availability -High specific work	-Expensive -Electrical yield is low at small sizes -Partial load decreases efficiency significantly

			-Plants are extremely large due to space requirements for condenser and boiler
Gas Turbine	15 – 25%	-Electrical efficiency is good even at small sizes - Compact assembly -Long maintenance intervals, high availability -Ideal for cogeneration plants (CHP) due to high exhaust temperatures	-Turbine components are exposed to combustion products -Partial load reduces efficiency significantly -Moderately expensive
Externally fired gas turbine	10 – 20%	-Turbine components isolated form combustion products -Electrical efficiency is acceptable even at small sizes - Long maintenance intervals, high availability - Ideal for cogeneration plants (CHP) due to high exhaust temperatures	-Expensive -heat exchanger is exposed to high temperature and aggressive combustion gases - Partial load reduces efficiency
Gas Engine	13 – 28%	-High electrical efficiency even at small sizes -relatively inexpensive -Durable and reliable -Partial load affects efficiency only marginally	-Engine components are exposed to combustion products -Short and expensive maintenance intervals, low availability

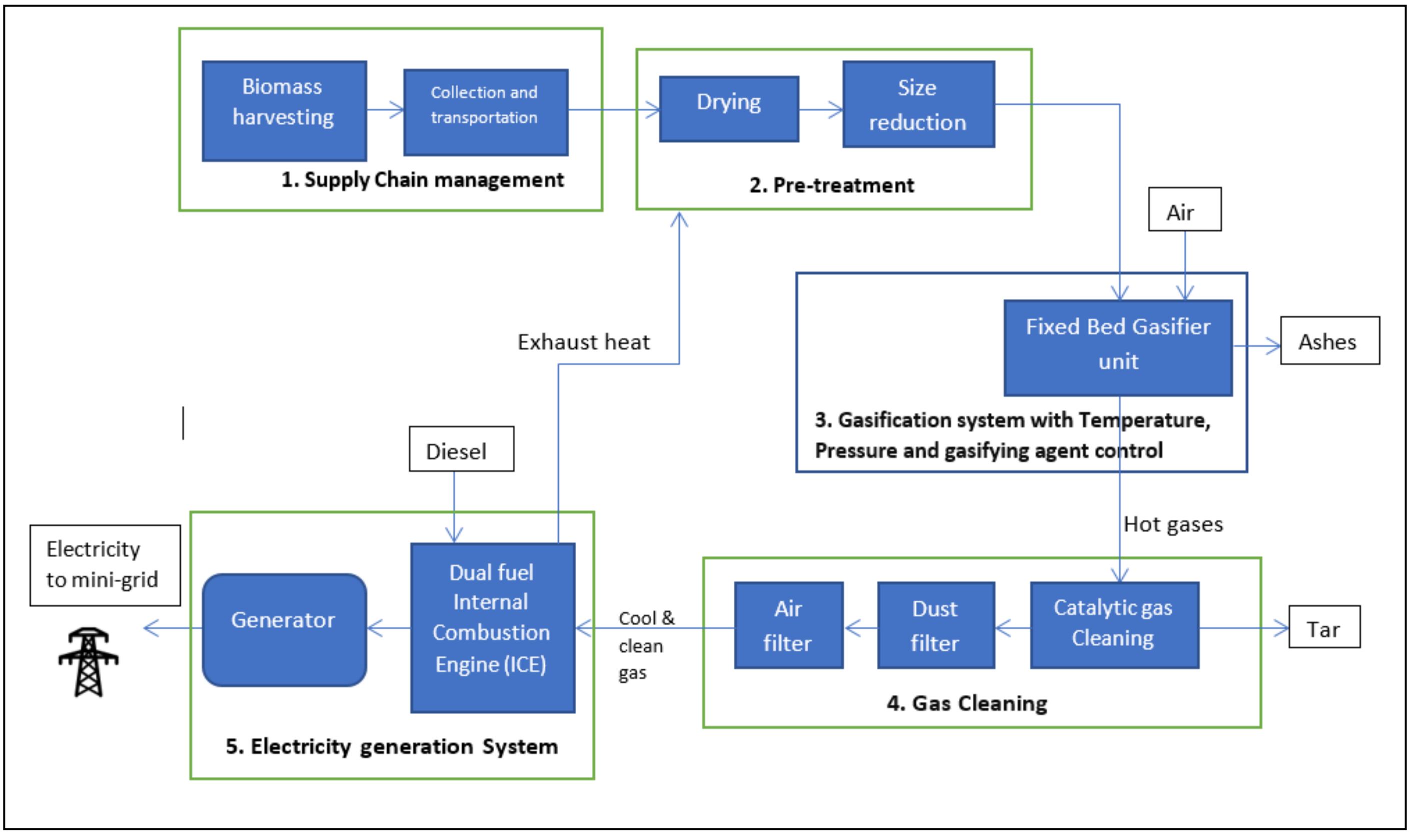
Source: [126]

Other inflows into the system are Temperature control, Pressure, Gasifying Agent, Air fuel ratio and equivalence ratio [115]

Flow diagram for the technical installation

The flow diagram illustration for the biomass gasifier based power project applicable to this thesis has been designed as in *Figure 4:5* below. This figure is an adoption and improvement of the "schematic of a typical biomass gasifier based power project" by Nouni et al., 2007 [117]

Figure 4:5: Schematic of the bamboo gasification plant for the thesis



4.3. ECONOMIC ANALYSIS

This section gives the details on estimated project costs and financial analysis.

The economic analysis is used to determine production costs and all its major components. It includes capital costs, operation & maintenance costs and expected revenues from the project [138].

4.3.1. Capital Cost Estimation

The two projects that were installed in Uganda on gasification technology were running with capital costs of $2,087 and $2,890 per kW respectively. These capital costs included Feasibility study, building, gasifier, gas engine, shipping, customs duty, insurance, clearance, fuel wood processor, wood processing shed, installation and commissioning, additional electricity controls, initial training and grid extension.

If we take the average of these two costs which is $2488.5 per kW

Knowing the fact that the technologies have decreased cost with time within the last 10 years, this must affect that cost downwards. But also, the money value of Uganda has gone down against the dollar in the last 10years, this means that most of the capital costs within Uganda would stand at higher value than they did 10 years ago. So, for the capital cost, we shall take it at **$2488.5/kW in 2017**.

4.3.2. Operation and Maintenance Cost Estimation

Estimation of bamboo feedstock and plantation cost in Uganda

There is no current data on costs of mature bamboo stem in Uganda. However, in the neighbouring Kenya, a mature stem/culm of bamboo (4 years) costs KSH40 which is equivalent to UGX 1387 and USD 0.385 [143]. Given that this is a mass production assured market project, and given the location, we shall assume the cost paid for each bamboo stem to be USD 0.1925, half of the price above.

Kigomo (2007) [143], indicates that 100 to 500 plants of bamboo can be planted on 1 hectare. Each of these plants, if well maintained, can produce a clump of 15 – 20 culms (bamboo stems). Considering the averages, therefore, we assume 250 plants per hectare with 17.5 bamboo stems. This will be equivalent to an expected yield of (250 X 17.5) =4,375 bamboo stems per hectare.

Therefore,

- Cost of bamboo stems on one hectare is (4375 X 0.1925) =USD 842.1875
- Cost of bamboo stems on required annual land cover would be (240.308ha X USD 842.1875) =USD 202,384.39

Therefore, the **annual cost of bamboo biomass** required is USD **202,384.39 /year.**

Other operating cost estimates

Direct costs considered

Raw materials: - The main raw materials for this project are bamboo biomass feed stock prices per year.

Consumables: -. Since the cost of consumables (additives, catalysts and adsorbents) is estimated to be usually less than 3% of the total operating cost [138]. We shall estimate at 1% of the total operating cost.

Effluent (Ash) disposal: - This project considers that ash will be disposed of in waiting for fertiliser making. There will be no costs considered for ash disposal in this context.

Utilities: Utilities required would be air and water. Since air is to be used as gasification medium, there will be no cost for it. This plant will be located near a water body, water is not sold in Bududa, therefore, we consider no costs on utilities.

Labour requirements: Salaries depend on region. The operator salaries of Uganda shall be estimated using the net average salary details of Uganda. The cost of living in Uganda data [148] indicates that average salaries of Uganda are UGX 605,000 per month per person. This translates into (605,000/ (30*24)) hours = UGX840 per hour per person.

Operation Labour = Labour hours X wage rate
Assuming in every operation hour, there are two operation technicians, and average operation machine hours per year are 7380 i.e. ((6000+8760)/2), Operation labour would sum up to (7380*2*840) UGX per year
=12,398,400UGXper year
=3,429.8 USD per year (based on UGX-USD change rate of 28/07/2017

Maintenance costs: - Include replacing, repairing parts, equipment, and costs of labour and supervision needed to carry out the maintenance work. Maintenance cost is estimated to be between 3 to 6% of installation and equipment investment. Plants with more moving equipment or more solids handling usually require higher maintenance [138].

Assuming that this is to be an equity investment, interest shall be zero.

The *table 4:5:* is an upgrade of Shah et al. 2016 [138] operational cost estimates, but applicable to Ugandan context

Table 4:5: Operating cost calculation

Operating Cost Parameter	**Figure and calculation procedure for excel**
Direct costs	
DFC	$2488.5/kW = $10,308,860.1 for 4.1426MW
Raw materials (biomass feedstock)	USD 202,384.39 per year
Effluent (Ash) disposal	0
Consumables (catalysts, adsorbents)	0.01 X (Direct + Indirect operating costs)
Utilities (fuel, electricity, steam, water, cooling agents)	0
Operating labour	USD 3429.8 per year
Operating supervision	0.2 X operating labour cost
Quality control	0.2 X operating labour cost

Maintenance labour	0.027 X DFC
Maintenance material	0.018 X DFC
Maintenance supplies	0.0075 X DFC
Indirect cost	
➢ **Fixed costs**	
Property taxes	0.02 X DFC
Insurance	0.01 X DFC
➢ **Plant overheads**	
Fringe benefits	0.22 X (operating labour + supervision)
Overhead	0.50 X (operating labour + supervision)
General cost	
Administrative	0.045 X Direct costs
Finance (interest)	0
Marketing	0.135 X Direct costs
Research and Development	0.0575 X Direct costs
TOTAL O&M COST	**Sum of all the above**

- From the excel sheet, the total non-discounted annual **Operation and Maintenance cost** of the BGPP excluding bamboo biomass feedstock costs and excluding the DFC is **USD 142,034.39**.

4.3.3. Levelised Cost of Electricity (LCOE)

The LCOE expression (vi) in section 3.2.3. is fed into excel using assumptions in *table 4:6* below.

Table 4:6: Needed assumptions for LCOE calculation

Item	**Assumptions and estimations**	**Source**
Discount rate	10%	IRENA (2012) [139]
Economic life of the gasification plant	20 years	IRENA (2012) [139]
Average operation machine hours per year	7380hours/year	Section 3.1.2
Equipment and capital costs	$2488.5/kW	Section 4.3.1
O&M costs without feedstock costs	USD 142,034.39 /year (see excel)	Section 4.3.2
Estimated feedstock costs	USD 202,384.39 /year	Section 4.3.2
The fraction of electricity losses in the local distribution network for Uganda (l)	7.6%	RECP (2015)

Electricity Delivered by the BGPP	1.14MW	Section 3.1.2

From the calculations in excel document, the **LCOE is 0.18486 USD/kWh** =666.42UGX/kWh (using online dollar rate of 29th/08/2017).

Comparing the LCOE with Feed in Tariffs of biomass projects (USD 0.103/kWh), the project would not be economically feasible. However, on comparison to the current cost of electricity for domestic consumption in Uganda (USD 0.19/kWh), the plant would be economically feasible. This means if the electricity was sold at the same charge as the current domestic charges, there would be some profit made.

4.3.4. Investment Analysis Results and Discussion

Refer to excel sheet (*appendix 4*)

- The NPV after 20 years is USD 367908.4. The NPV is greater than zero, meaning that this project is economically feasible.
- The IRR for the cash flows is 10.5195%. This is only slightly greater than the discount rate of 10.0%. The BGPP is economically feasible.
- The Payback period is 8.22 years
- The discounted Payback period is 18.04 years.

From this analysis, it is clear that the economic feasibility of this BGPP for electricity generation is existent but not so significant. The heat recovered has not been assessed economically because it will be consumed by the power plant itself for biomass drying.

Result summary of section 4:2, Economic analysis

Parameter		**Result**
1	Estimated number of bamboo stems per hectare	4,375 bamboo stems/ha
2	Estimated cost of each mature bamboo stem/culm	USD 0.1925
3	Cost of bamboo biomass feedstock per year	USD 202,384.39 /year
4	Capital costs	USD 10,308,860.1 for 4.1426MW
5	O&M costs (excluding feedstock)	USD 142,034.39
6	Annual electricity delivered by gasifier	1.14 MW
7	Estimated power output capacity of the BGPP	4.1426 MW
8	LCOE	0.18486 USD/kWh
9	NPV	USD 367908.4
10	IRR	10.5195%

11	Payback period	8.22 years
12	Discounted Payback period	18.04 years

4.4. RISK ASSESSMENT

Table 4:7: Project risk assessment and risk mitigation options

	Possible risks	**Risk Mitigation techniques**
1	Financial risk	
	Lack of sufficient capital investment which could lead to slower project implementation	Breaking down the project into phases to spread the capital investment
	Poor project management resulting into higher overall costs for example due to possibility of corruption within the project workers	Recruiting a highly qualified project management head team and putting in place strict management principles and guidelines
2	Environmental risk	
	Failure to manage the bamboo farms making them spread extensively and take up cultivation land	Sufficient training and timely payment of biomass farmers to keep them motivated.
3	Technical risk	
	Challenge with limited experience with gasification technology of Ugandan employees which could cause system errors especially in the start	Sufficient training and having at least two highly qualified technicians.
	Delays in maintenance resulting into running systems in less optimal state thus decreased efficiency and decreased power production	Timely maintenance and replacement of spares
4	Social risk	
	Aesthetic and inherent risks; Mere rejection of the bamboo based project by the locals	Carrying out massive sensitisation and involvement of the local community at almost all stages of planning and implementation of the project to reduce risk of social rejection.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

Outline:

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5.1. CONCLUSION

5.1.1. From the Literature Review

Uganda is strategically located within the centre of the great lakes region and has generally good weather with moderate average yearly temperatures ranging within the 20's (ºC), fertile soils and rainfall almost throughout the year. This favours vegetation cover and farming in almost all parts of the country. Climate change is however affecting Uganda just like many other countries threatening temperature rise and inconsistent rainfall patterns. This is predicted to impact especially the agricultural sector which Uganda relies on almost entirely. Much as the country has a high resource base including which are mineral deposits, numerous rivers and lakes besides the great weather, poverty rates are still very high. There is a high rate of unemployment especially among the youth who make up the highest percentage of the population. The economy's reliance on majorly rudimentary forms of Agriculture is no longer sustainable.

There is therefore need to utilise the huge resource base of Uganda to increase income sources but sustainably. This would improve the livelihoods of the people while positively impacting on the environment to mitigate and also increase adaptability to climate change. The industrial sector especially needs to be developed using clean energy, to sustainably create jobs and income. Production of export-worth goods would increase the country's productivity and GDP whence forth, therefore increasing economic stability on the international scene. Energy provision and well as job creation in the rural areas would lessen rural-urban migration and also lead to quicker development of currently poverty-stricken regions of the country.

In order to accelerate development and decrease poverty, it is necessary to boost electricity access. Uganda's electricity sector is lagging behind with less than 10% total electrification of the country and with many rural areas still having no access to electricity. According to plans, only about 26% of the rural areas of Uganda (covering more than 80% of the population) are in plan to be having access to electricity by the year 2022. Even with the current low supply of electricity, electricity demand is estimated to be growing at a rate of 10% per year. Dependency on hydro power which is currently supplying the biggest share of electricity is unreliable and unsustainable and more forms of electricity supply urgently need to be explored. More innovative forms of energy supply especially for rural electrification need to be put in place.

Given the relatively good nature of the soils and the climate, biomass energy is found to grow faster in many regions of Uganda assuring a great supply source for bioenergy. However, much as Uganda has a lot of biomass supply already, it is still found necessary to diversify with other forms of biomass to boost the biomass supply especially for use in better energy conversion technologies.

Climate change effects are currently already experienced in Uganda but exacerbated by the high poverty levels within the country. Early adaptation mechanisms and climate change mitigation techniques must be employed in time therefore.

Introduction of the unique, fast growing bamboo can be one of the solutions to achieving their target increase forest cover from 15% to 18% by 2021 and 24% by 2040. Also, bamboo growth and utilisation has the potential to reduce pressure of utilising slower growing plants and trees within Uganda. The bamboo plant requires minimal maintenance especially in its first two years in comparison to other plants and its biomass production can be assured whole year round.

From the several case studies of bamboo plant being used as a source for economic development and transformation of rural areas. It is concluded that bamboo plantation and utilization in mountainous regions can possess a more competitive source of cash based income than other sources of income from lands and farm based activities. Regardless of when the bamboo adaptation for plantation and industrialization is initiated, the bamboo sector has the potential to be adopted fast enough to significantly contribute to forest based cash incomes. Case studies also indicate that once bamboo is well adopted, market for its products is well available and also bamboo cultivation is an investment and form of asset that can assure high incomes through future affordability of other high investment projects.

Bamboo is a great source of biomass for gasification plants with an energy content averaging at 18MJ/kg. Bamboo is at times preferred compared to other bioenergy plants due to the fact that bamboos have Nitrogen and Sulphur content lower than that of other potential bioenergy plants, leading to a smaller exhaust of the pollutants nitric oxide and sulphur dioxide. Moreover, the quality of syngas from bamboo plant can further be enhanced when gasification of bamboo is done at lower temperatures and in presence of steam.

The challenges associated with large scale bamboo cultivation and use as a biomass resource can all be solved by choice of an ideal location for bamboo plantation, preferably a vast piece of land deemed unsuitable for crop farming or settlement.

Biomass gasification especially fixed bed technology is a mature technology which has been used for more than a century to produce both power and heat in both the developed and developing world. As fossil fuels are increasingly getting phased out, more research and development for application of biomass for bioenergy is growing and many gasification systems based on bio-energy have been installed worldwide. For example, gasification has already been playing a key role in remote and rural electrification especially in Asia. Literature proves that mainstreaming small gasifiers for rural and distributed power generation using reciprocating engines and micro turbines is very operationally feasible. Power gasifier systems based on especially fixed bed gasification technology for under developed and developing countries, along with catalytic gas cleaning offer a viable option for the developing world. Power capacities even way above 5MWe are produce-able with improved biomass technology such as use of IGCC. One assessment study of 1981 considered Bamboo as one of the potentially good fuel for especially downdraft gasifier systems.

The only gasification systems that were installed in Uganda before were supplied by Indian companies. These systems were also characterised by very low efficiencies.

5.1.2. On the Bududa Case Study Analysis

Due to the fact that Uganda has only 0.4 ha arable and pasture land per capita and is a net food importer, biomass intended for bio-power systems is suggested to only be restricted to marginal sites or combined with agriculture. It is necessary to choose a location with availability of marginal land.

Based on its physical, economic and social characteristics, Bududa district in Eastern Uganda is one of the most favourable locations for such a bamboo based sustainable project. It is located in the mountainous ranges of Mount Elgon. The people in Bududa already know about Bamboo species since it natural grows in the region and the local population have had it within their cultural consumption for over 3000 years. This means that social acceptability of bamboo is more likely. The topography, water existence and nature of the soils make this region susceptible to a common disaster of landslides and a considerable land area of the district unsuitable for settlement and agriculture.

This district has a lot of land un-fit for population settlement or Agriculture due to steepness of the slopes and soil characteristics. This land is available for better economic options. The land provides suitable characteristics for bamboo growth for better land use and reclamation, as well as prevention of soil erosion, landslides and better environmental conservation in general. Most of the occupants of Bududa (86.4%) are subsistence farmers who are facing problems due to poor topographic characteristics of the land and soil erosion. These farmers could be provided with better options of income generation through bamboo commercial farming on the un-utilised land. In conclusion, the economic situation of the district provides a suitable situation for a bamboo based economic initiative.

5:1.3. Based on the Result Analysis

The sustainable bamboo based concept for rural economic growth suggested by this thesis is applicable to Bududa district and has potential of meeting at least 15 of the 17 Sustainable Development Goals (SDGs). This can assure increased income and also give some guarantee that the local population will be able to afford the generated electricity by the BGPP within the same concept. It is possible to make up to $12,000 from each hectare per year by the bamboo plant dealers and processors.

Bududa district requires a load of 1.14MW to satisfy its district rural needs once provided with electricity. The sectors to be supplied with electricity are mainly households, health centres, academic institutions and the local government with each having electricity supply share of 93.7%, 0.84%, 4.18% and 1.27% respectively. The household sector being the biggest consumer of electricity gives a typical rural load profile with highest energy consumption for lighting in the morning hours to prepare for the day and in the late evening and early night time.

It is technically feasible to install a Biomass Gasifier Power Plant for this district due to especially the suitability of the location to assure continuous supply of bamboo biomass the whole year round. The technology of gasification is developed and has been used in Uganda before, it is therefore possible to obtain a good supply of equipment for installation of the gasifier especially through importation of the plant parts. There is also availability of labour to run the BGPP and an assured market for the generated electricity.

The Capital costs for installation of the BGPP would be $2488.5 per kW, the operation and maintenance costs $142,034.39 and the cost of bamboo feedstock for the BGPP would be $202,384.39 per year. The land requirements for bamboo plantation specifically for the BGPP are very small. 240.308 hectares of land per year are needed. This translates into only about 0.88% of the total land area of Bududa district required specifically for running the BGPP year-round. This has potential of leading to about 60,077tons of carbon stored each year and about 1,225.57tons of carbon absorbed by the bamboo plants per year.

Since the unit cost of electricity production (the LCOE) is 0.18486USD/kWh, and the feed in tariffs for biomass projects is 0.103 USD/kWh, the BGPP cannot be able to produce power that is competitive with the feed in tariffs of Uganda. This is however not a problem because the national grid does not reach majority of the land area of Bududa.

However, if the BGPP sells electricity directly to consumers at the same charges as the 2017 grid connected electricity of 0.19USD/kWh, the BGPP will be economically feasible with a Net Present Value of USD 367908.4, the Internal rate of return of 10.5195% greater than the discount rate by 0.5195%, a Payback period of 8.22 years and a discounted Payback period of 18.04 years. This is all possible with an initial investment of USD 10,308,860.

5.1. RECOMMENDATIONS

Given that there is a small margin between the LCOE ($0.18486per kW) and the selling price of electricity from the BGPP ($0.19), giving a relatively small Net Present Value of USD 367908.4 at the end of the lifetime of the plant, an IRR of only 10.5195% (discount rate=10%) and a long payback time. This BGPP project as assessed in this thesis should therefore not be recommended to an investor interested in big profits. It can instead make more sense if support credit schemes are employed instead for example implementing it as a government initiative or a donor initiative.

On the other hand, if all the benefits of the bamboo based sustainable project are assessed, the overall bamboo based project within which the gasification plant is set up may make more economic viability especially to the local population and the government. It is therefore recommendable that for future research, the overall benefits of the bamboo sustainable project suggested by this thesis is holistically quantitatively assessed.

Cost reduction of the BGPP can be achieved if ways of obtaining the bamboo biomass at cheaper costs are explored especially after installation. For example, if the BGPP is installed within the suggested sustainable concept, feedstock costs can be cut by utilisation of waste material from bamboo product markets. Recycling ash to fertilisers and selling it off can be another way of creating income.

In order to assure an organised constant supply of bamboo biomass, a concept of biomass procurement involving local out-growers in a community based association as suggested in section 4.2.3 of this document is recommended.

There is need for installation of systems with close monitoring by highly skilled technical staff to ensure constant mechanical functionality to maximise power output and efficiency of the systems. This is because previous gasification systems installed in Uganda failed to operate feasibly because of running with very low efficiencies especially due to technical complications.

Larger scale gasification systems are more recommended for electricity generation in order to maximise on the economies of scale and thus achieve a lower Levelized Cost of Electricity. An Integrated Gasification Combined Cycle (IGCC) system as described in section 2:3:5 of the report is recommended as an installation for the larger scale gasification system in order to also increase on the efficiency.

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Appendix

1. Number of technology development sites and potential power consuming sectors/ enterprises in Bududa

Sub-County	Type of Enterprise	No. of FGs benefiting	Estimated H/Hs Directly benefiting
Bududa	Aquaculture Coffee Poultry Piggery	39	195
Bulucheke	Coffee	43	215
Bubiita	Coffee Bananas Poultry	80	400
Bushika	Coffee Banana	62	412
Bukigai	Coffee Banana	62	310
Bukibokolo Town Council		21	119
Bumayoka	Coffee Banana	24	120
Total		**331**	**1,771**

Source: [99]

2. Examples of Swedish suppliers of palletization equipment and the equipment capacity to produce pellets

Supplier	Type of supplier	Brand/model	Capacity (kg/h)
Sweden Powers Chippers AB (SPC)	Manufacturer	SPC	100-500
Biopress AB	Manufacturer	Biopress	100-800
PM Bioenergi och Smide	Reseller	BT-press	150
SvenskEkoDiesel	Reseller	Ekopell	200-1000
Morums Mekaniska	Manufacturer	Morumspressen	50
Mared AB	Reseller	Munch	150-5000
Roland Carlberg processytem AB	Reseller	KAHL	300-8000
UNY Konsult	Reseller	Salmatec	450-950

Source: [126, 138]

3. Estimates on gasification capital cost break down by Mott McDonalds (2011)

Item	**Estimated cost per kW**	**Wood gasification proportion of cost (%)**
Consultancy/Design (project development, consent and planning)	258	6
Civil works (engineering and construction charges)	559	13
Feedstock handling /prep (sorting, drying, processing & blending)	245	6
Electrical/ Balance of plant (connection of plant to grid/mini grid & required equipment	172	4
Converter system (gasifier, connection systems, gas cleaning systems)	2,679	62
Prime mover (power generation technologies i.e. converter & generator)	387	9
TOTAL	**4,300**	**100**

Source: Mott MacDonald’s (2011) [122]

4. EXCEL SHEET

Operating Cost parameter	Unit	Total of 20 years lifespan (n)	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Summation
Direct and Indirect costs																								
Capial cost expenditures (It)	USD		10308860.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Biomass feedstock expentidures (Ft)	USD			202384.39	202384.39	202384.39	202384.39	202384.39	202384.39	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	202384.4	
Operating labour	USD			3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	3429.8	
Operating Supervision	USD			685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	
Quality control	USD			685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	685.96	
Maintenance labour	USD	278339.2227		23194.935	23194.935	23194.935	23194.935	23194.935	23194.935	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	23194.94	
Maintenance material	USD	185559.4818		15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	15463.29	
Maintenance supplies	USD	77316.45075		6443.0376	6443.0376	6443.0376	6443.0376	6443.0376	6443.0376	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	6443.038	
Property taxes	USD	206177.202		17181.434	17181.434	17181.434	17181.434	17181.434	17181.434	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	17181.43	
Insurance	USD	103088.601		8590.7168	8590.7168	8590.7168	8590.7168	8590.7168	8590.7168	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	8590.717	
Fringe benefits	USD			905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	905.4672	
Overhead	USD			2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	2057.88	
Consumables	USD			2810.2287	2810.2287	2810.2287	2810.2287	2810.2287	2810.2287	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	2810.229	
General Cost																								
Administrative	USD			11479.392	11479.392	11479.392	11479.392	11479.392	11479.392	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	11479.39	
Marketing	USD			34438.176	34438.176	34438.176	34438.176	34438.176	34438.176	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	34438.18	
Research and Development	USD			14668.112	14668.112	14668.112	14668.112	14668.112	14668.112	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	14668.11	
Total O&M Expenditures (Mt)	USD			142034.39	142034.39	142034.39	142034.39	142034.39	142034.39	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	142034.4	
Electricity delivered (Et)	kWh		0	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	8413200	
discount rate (r)	%	10																						
Discounting factor (d) = (1+r)^t			1	1.1	1.21	1.331	1.4641	1.61051	1.771561	1.948717	2.143589	2.357948	2.593742	2.853117	3.138428	3.452271	3.797498	4.177248	4.594973	5.05447	5.559917	6.115909	6.7275	
Discounted lifetime costs (It+ Mt +Ft)/d	USD		10308860.1	313107.98	284643.62	258766.93	235242.66	213856.96	194415.42	176741.3	160673.9	146067.2	132788.3	120716.7	109742.4	99765.85	90696.23	82451.12	74955.56	68141.42	61946.75	56315.22	51195.66	13241091.31
Discounted Electricity generation (Et)/d	kWh		0	7648363.6	6953057.9	6320961.7	5746328.8	5223935.3	4749032.1	4317302	3924820	3568018	3243653	2948775	2680705	2437004	2215459	2014053	1830957	1664507	1513188	1375625	1250569	71626314.03
LCOE	USD/kWh	0.184863503																						
CALCULATING NPV, IRR and Payback time																								
Selling Price of electricity generated	USD/kWh	0.19																						
Total income i.e. Elecricity Sales (un-discounted), S			0	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	1598508	
Cash flows (sales - expenditures) =(S-Mt-Ft)			-10308860	1254089.2	1254089.2	1254089.2	1254089.2	1254089.2	1254089.2	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	1254089	
Discounting cash flows			-10308860	1140081.1	1036437.4	942215.79	856559.81	778690.74	707900.67	643546.1	585041.8	531856.2	483505.7	439550.6	399591.5	363265	330240.9	300219	272926.4	248114.9	225559	205053.6	186412.4	
NPV				-9168779	-8132342	-7190126	-6333566	-5554875	-4846975	-4203429	-3618387	-3086530	-2603025	-2163474	-1763883	-1400618	-1070377	-770158	-497231	-249117	-23557.6	181496	367908.4	
IRR		10.5195%																						
Cumulative cashflow (**Payback period**)	years	8.22		1254089.2	2508178.4	3762267.7	5016356.9	6270446.1	7524535.3	8778625	10032714	11286803												
Cumulative discounted cashflow (**Discounted Payback period**)	years	18.04		1140081.1	2176518.5	3118734.3	3975294.1	4753984.8	5461885.5	6105432	6690473	7222330	7705835	8145386	8544977	8908242	9238483	9538702	9811629	10059743	10285302	10490356		