Economic Evaluation of Bamboo Cultivation and Potential Yield on Rehabilitated Mine Sites

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DECLARATION

I declare that this research report is my own unaided work, unless otherwise stated and acknowledged. It is being submitted for the degree of Masters of Science in Metallurgical Engineering (Coal Sciences) to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other university.

Signed: …………………….. on this ……. day of ……………….., year ……………..

ABSTRACT

Abandoned mines in South Africa have created a series of environmental legacies around the mining community in the form of health hazard (air pollution), land degradation and illegal mining activities. The biggest mine environmental legacy that is being addressed today in South Africa is that of abandoned mines, particularly asbestos and the process of cleaning up asbestos mining dumps in South Africa as implemented by Mintek (state owned mineral processing and metallaurgical research instistute)on behalf of Department of Mineral Resources (DMR) and this form the main basis of this research study.

The history of abandoned mines, particularly asbestos mining, is that the mining peaked and took place during the time when there were no environmental regulations forcing mining companies to take control of their waste. The only legislation was the Atmospheric Pollution Prevention Act (Act No.45 of 1965). The Mineral Act, which regulated most of the mining activity in South Africa was promulgated in 1991 and was enacted as Act No.50 in 1991.
Apart from the environmental challenges, these mines are located in rural areas with high unemployment levels and poor infrastructure, and therefore all solutions would require these matter to be addressed as well. This study was based on a literature review involving bamboo as a potential vegetation cover to be grown on abandoned mineland both for rehabilitation and with intention to harvest it for energy use. This would hope to address some of the socio-economic issues within the communities surrounding such abandoned asbestos mines. Penge area in the Limpopo Province is proposed as the site for a pilot study for such bamboo cultivation.

Bamboos are a large group of rapidly growing woody grasses, mainly found in the Indo-China regions of the world that can be sustainably managed in short-cycle harvesting schemes. They offer many benefits like erosion control, architectural properties for rural construction activities and can be used as biomass feedstock for the bioenergy economy. The results of this study indicate that it is possible to grow bamboo in the Penge based on its physio-climatic conditions. The literature review proposes , *Bambusa balcooa, Dendrocalamus asper*, *Dendrocalamus strictus* and *Phyllostachys edulis* as suitable bamboo species for the region. Based on rudimetary simple evaluation model the area will produce 14 tonnes/ha/year of biomass in the 5th year of harvesting, increasing to and stabilizing to 47

tonnes /ha/year in the 7th year and it has proven economically feasible to proudce energy from the amount of feedstock generated.

DEDICATION

I would first like to thank my wife Mabatho Mothapo and my two beautiful daughters, Kgonagalo and Thakgalo, for giving me all the love and support during difficult times when going through my studies.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACRONYM/ ABBREVIATION	DEFINITION
%	Percent
€	Euro
AMD	Acid Mine Drainage
ARR	Accounting Rate of Return
BEC	Biomass Energy Centre
c/kWhr	Cents per Kilowatt Hour
CaO	Calcium Oxide
CGS	Council for Geoscience
CHP	Combined Heat and Power
CNY	Chinese Yuan
cm	Centimetre
CM	Carbuscular Mycorrhizal
CO_2	Carbon Dioxide
CSMI	Centre for Sustainability in Mining and Industry
DAP	Diammonium Phosphate
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DOE	Department of Energy
DST	Department of Science and Technology
DWAF	Department of Water Affairs
EEP	Environment Energy and Poverty
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMPR	Environmental Management Programme
EPCM	Engineering, Procurement and Construction Management
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
Gefco	Griqualand Exploration & Finance Company
GHG	Greenhouse Gas
GIS	Geographic Information System
GJ	Gigajoule
GJ_{TH}	Gigajoules Thermochemical Unit
GWh_{el}	Gigawatt hectare electricity
GWh_{th}	Gigawatt hectare thermal
ha	Hectare
HDSAs	Historically Disadvantaged South Africans
hrs	Hours
HSRC	Human Science Research Council
IAS 41	International Agriculture Standard review no 41
IDC	Industrial Development Corporation
IDP	Integrated Development Plan
INBAR	International Network for Bamboo and Rattan

ACRONYM/ ABBREVIATION	DEFINITION
IRR	Internal Rate of Return
J	Joule
K	Potash
Kg	Kilogram
kJ	Kilojoule
kW	Kilowatt
kWhr	Kilowatt hour
KZN	KwaZulu Natal Province
LP	Lump Sum
m	Metres
MCM	Mine Closure Model
MgO	Magnesium Oxide
MJ/kg	Mega Joules per Kilogram
Mm	Millimetre
MPRDA	Mineral and Petroleum Resources Development Act
MW	Megawatt
N	Nitrogen
NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
P	Phosphorous
pH	Measure of Acidity and Alkalinity
PI	Profitability Index
PMBOK	Project Management Body of Knowledge
RDP	Reconstruction and Development Policy
RES	Renewable Energy Solutions
SADC	Southern Africa Development Community
SONA	State of the Nation Address
SSA	Sub-Saharan Africa
t/ha	Tonnes per hectare
Tg C	Teragram Carbon =10^{12} grams of Carbon
UK	United Kingdom
US$	United States Dollar
USA	United States of America
yr	Year
ZAR	South African Rand

CHAPTER 1: INTRODUCTION

South Africa has a long history of asbestos mining that ended with the imposition of the legal embargo on the mining of asbestos in 1999, due to its extreme health hazards (Nedlac, 2002). In early 2000, the then Department of Minerals and Energy (DME) commissioned a research study to gain a baseline understanding of the extent of the problem of derelict and ownerless asbestos mines, estimate the costs of the closure and pilot the implementation of rehabilitation programmes (DMR, 2014 internal Report). The rehabilitation of derelict and ownerless asbestos mines is a consequence of poor environmental legislation in the early years of mining in South Africa and has resulted in national government assuming responsibility for the rehabilitation of these mines in order to contain environmental and health hazards. By 2012, a total of 4 378 derelict and ownerless asbestos mines were identified, verified and ranked by the Council for Geoscience (CGS) from the initial list of 6 095 derelict and ownerless asbestos mine sites developed by the former DME in 2008 (DMR, 2013).

Coupled with the foregoing environmental challenges caused by the legacy of mining, South Africa is also faced with the problem of energy shortage and serious poverty levels, among other social ills which affect mainly rural areas, where most of these mining activities took place and/or are currently taking place. South Africa's energy sector is largely dependent on coal, with about 92.8% of its electricity generated from coal (SA Road Map, 2013). Coal is known among all other fossil fuels as the highest emitter of CO_2 emissions in South Africa and has been noted to have increased tremendously, with 85% of country's total 119Mt emissions generated from coal (Boden, Marland and Andres,2011).

There are currently many solutions being proposed by different people under different fields in South Africa to address the challenges associated with the mine environmental legacy associated with asbestos on a political level. However, there is insufficient literature published that gives solutions that can address the legacy by addressing environment, energy and poverty trilemma (EEP) within the rural communities surrounding the derelict and ownerless mine sites. A report written by Landu landu and Mashai from Mintek (State owned metallurgical and mineral processing laboratory research institute of South Africa) , the rehabilitation of derelict and ownerless asbestos mining sites has been ongoing since 2009. In June 2013, the Department of Mineral Resources(DMR) and Mintek signed a contract effective 1st April 2013 wherein Mintek will manage the implementation of rehabilitation programmes for several identified derelict and abandoned mines in South Africa. These types of projects are executed by contractors appointed through the public tendering system. In an effort to promote sustainable rehabilitation, an indigenous plant called Mononto or Kraal Melkbos (*Euphorbia tirucalli)* and mixture of seed grasses provided by the likes of Agricote Advanced seeding (*Antephorapubescens;Cenchrus cilliaris;Cynodon dactylon;Digitaria criantha;Enneapogon cenchroides;Eragrotis curvula; Erogrotis teff; Heteropogon contorius and Pogonarthria squarrosa*) are currently being grown and recommended by many civil engineering contractors in most abandoned sites in the eastern Limpopo Province , Mpumalanga Province and Northern Cape Province to protect newly rehabilitated mine sites from erosion.

The challenge with the aforementioned monoto plant species is that it is poisonous to both animals and humans, and therefore, it is not suitable for grazing and does not offer any forest advantages to local communities such as providing wood for fire, other than simply acting as an erosion control (Mintek Internal Communication Report, 2013). In this study, a literature review was conducted by gathering information over the world to promote sustainable rehabilitation with economic potential by solving mining and environmental legacies associated with abandoned mines considering bamboo as a plant to be grown on rehabilitated mine sites. The alternative plant “bamboo” being investigated in more detail in this study is the use of different species of bamboo in the rehabilitation of abandoned mines. The planting of bamboo has been proven elsewhere in the world to be a fast-growing, soil-tolerant plant (Hunter, 2003) that has considerable benefits through its multiple uses, one of which is the provision of feedstock for the generation of biomass, which has the potential to alleviate many of the energy challenges that South Africa is experiencing currently.

1.1 Background and Motivation

South Africa has an energy-intensive economy that is significantly dependent on coal for the production and supply of electricity. Coal provides about 80% of the country’s primary energy needs, supports 92.8% of the electricity generation, provides feedstock for the country’s synthetic manufacturing plants, and as a fuel in the steel, cement, and brick manufacturing industries (Nkomo, 2005). While the country’s coal reserves are large and provide an inexpensive source of energy, the ageing electricity generation, including poor maintanance and distribution infrastructure coupled with the limited availability of alternative energy sources has resulted in mismatches between supply and demand of electricity in the economy. The widespread power shortages that South Africa has been experiencing since 2008 highlighted the risks that are inherent in this heavy dependence on coal and urgent need to diversify the energy mix by including renewable energy sources, particularly wind, solar and biomass energy (World Energy Council, 2006).

The energy challenges that South Africa is experiencing can be alleviated by the cultivation of bamboo plants on derelict and ownerless asbestos mine sites which will, in turn, be used to produce biomass for co-firing with coal or used independently as a crop for the generation of electricity. There is a significant scope for South Africa to move away from the non-renewable conventional method of electricity generation to biomass-sourced energy, which is considered to be cleaner in terms of producing lower emissions, thereby protecting the atmospheric environment. The bamboo plantations have a potential to provide a source of income for microenterprises and livelihoods for the rural communities (Phimmachanh, Ying and Beckline, 2005) and this can be applied to surrounding communities affected by the abandonment of mining activities, and this was reviewed in this study.

This research study aims to investigate the economic viability of growing bamboo plants on rehabilitated mine sites which will, in turn, provide feedstock biomass for different end applications. In addition, the study utilises data available in the literature to make assumptions and develop projections to estimate the quantity of biomass that can be produced from specific areas of land. The challenges experienced in rehabilitating derelict and ownerless asbestos mine sites through analysing vegetation problems are highlighted in the rehabilitation framework (Figure 2-2) developed by Fourie and Brent (2006).

1.2 Poverty in the Rural Areas of South Africa

It is quoted in the Human Research Council (HSRC) report of 2014 that poverty has remained topical in the global development policy endeavours, especially in developing countries (Liton ,Sadekin and Muzib, 2014). It is much more topical in South Africa due to the historical depth of inequality in assets, income and opportunities. There are two reasons for studying poverty in any country: (1) it is ethically unacceptable, and (2) poverty affects the pace and the spread of economic growth (Ravallion, Chen and Sangraula, 2009). Most poverty in South Africa is in the traditional rural lands (39%), urban informality (28%) and rural settlements (26%). Limpopo Province, Eastern Cape Province, KwaZulu-Natal Province and Northern Cape Province have a lion share of this poverty, and coincidentally, these are areas where mining took place and/or takes place and where a number of abandoned mines, especially asbestos mines, are located.

1.3 Energy Challenges in South Africa

South Africa is ranked by the World Bank as an 'upper-middle income' country that had a gross domestic product (GDP) of R3384 billion and per capita income of approximately R110860 in 2013 applying 2013 annual avarage USA dollar to rand exchange rate as per appendix (OECD, 2013). The country is an important hub in the global mining value chain, supplying a variety of minerals to the global commodities markets, a regional assembly hub in the global automotive value chain and a key player in the regional finance and retail value chains. It is estimated that more than 50% of the South African population lives below the poverty datum level, which is confirmed by the Gini coefficient of 0.65 according to statistics for 2010 (HSRC, 2014). The economic growth rate declined to 2% in 2013 compared to the 2.5% economic growth rate experienced in 2012. While average GDP growth rates have been modest in recent years, per capita incomes are far higher in South Africa than elsewhere on the African continent (OECD, 2013). The sluggish recovery of the global economy, particularly in the European Union (EU) and the United States of America (USA) since the 2008 economic crises coupled with declining commodity prices has resulted in the South African economy, not growing at a rate fast enough to reduce poverty, inequality and unemployment in the country (www.africaneconomicoutlook.org 2016).

The South African economy produces and uses a large amount of energy and is dominated by the extraction of raw materials and primary processing industries (Kohler, 2006). The upstream and downstream energy sector contributes approximately 15% to the country's GDP and employed a labour force of over 250 000 people in 2013 (International Energy Agency,2014). Compared to other sub-Saharan African countries, South Africa has the highest per capita consumption of electricity due to the high energy demand from the mining and manufacturing sectors. The widespread power shortages that South Africa has been experiencing since 2008 are a result of the heavy reliance on coal as a source of energy in the country, ageing electricity generation, and distribution infrastructure and maintenance backlogs on most of the leading power generation plants. Since 1994, the government has made 'access to electricity for all' fundamental in its development policy. This is bearing fruit, with rural households that have access to electricity increasing from 49% in 2001 to approximately 68% in 2013 (DOE, 2015).

South Africa relies on coal for its electricity supply, and the current data suggest that sufficient coal resources are available to supply all required grades of coal for power generation in the central basin until July 2020. But there is significant uncertainty associated with timing, capacity and projected qualities of new mines and the delay associated with cost overruns of new power plants like Medupi and Kusile, a new scenario was built to alleviate this uncertainty (SA Road Map, 2014). The South African Coal Roadmap (2013) only identified renewable sources of energy such as solar and wind as alternatives to coal and biomass is not included in this report. However, the South African President's State of the Nation Address (SONA) in February 2014 identified biomass as an alternative energy source to coal. A committee of researchers was selected by the DOE to investigate the feasibility of harnessing biomass as an energy source, particularly in rural communities (DOE, 2015). A study is proposed on the growing of bamboo plants on rehabilitating asbestos mine sites which will, in turn, be used as feedstock in generating biomass energy which will fill the information gaps that were missed by the South African Coal Roadmap technical committee.

The energy challenge is at the forefront of issues facing policymakers in South Africa. The need to expand the electricity supply as part of the drive towards energy inclusion is very important, especially in far rural areas in developing countries (Pereira,Freitas and da Silva, 2011). Energy is essential in driving economic growth in the manufacturing sector, reducing the burden of diseases, poverty and meeting the Millennium Development Goals (Modi,McDade,Lallement and Saghir, 2006). The Rethinking Biomass Energy in sub-Saharan Africa (2009) study maintains that beyond 2015, the outlook for access to modern energy services in sub-Saharan Africa (SSA) will remain bleak, with electricity supply and distribution in decline in many SSA countries (Eleri and Eleri, 2009). A significant proportion of the nearly one billion people in SSA will rely on traditional biomass instead of more expensive forms of renewable energy sources (solar, wind and wood) by 2030. Policymakers in many SSA countries have been urged to start investigating ways of growing and harvesting feedstock materials for biomass generation.

South Africa, like many emerging economies, including China, Brazil and India has successfully implemented a national electrification programme as part of its Reconstruction and Development Policy (RDP) programmes adopted in 1994. Electricity use, which had been the preserve of the privileged few before the advent of democracy in 1994, has been rolled out to townships and rural areas where the majority of historically disadvantaged South Africans (HDSAs) stay. However, the success of the electrification program has been constrained by the slow uptake of this basic service. The consumption of electricity in rural communities averages 100 kWh/month per household compared with Eskom's target consumption of 350 kWh/month (Pereira *et al.*, 2011). At current consumption rates, the initial investment outlay in electricity distribution infrastructure cannot be recouped in 20 years.

1.4 Sources of Biomass

Biomass is basically defined as a biological material derived from living or recently living organism. In the energy context, it usually refers to plants material, but it also refers to animal and vegetables material (Biomass Energy Centre, 2006). Filho and Badr (2004) described biomass as agricultural and forestry residues, municipal solid waste and manufacturing waste, vegetable oils and dedicated energy crops like sugar cane bagasse or virgin wood and wood residues. Biomass energy comes in different forms, and the various fuels derived from biomass are collectively called biofuels (Sarfo, 2008). Globally, a variety of plants are being investigated as a possible feedstock for biomass energy, and these include switchgrass, maize, soya bean, rapeseed, poplar and sunflower, and bamboo among others (Lewandoski, 2006).

1.5 Biomass Cultivation on Rehabilitated Mine Sites

Various authors have investigated the suitability of *Miscanthus* species for managing organic and inorganic contaminated land and ecosystem. It is a suitable species for managing contaminated land, in that it has the ability to sequestrate contaminants into its root system and also because it is not invasive and highly productive. This option was recommended as the best and most economical way of mitigating environmental hazards on land instead of using physio-chemical options of remediation (Nsanganwimana,Pourrut,Mench and Douay,2014). *Miscanthus* species were found to offer potential as an energy feedstock, building materials, biomass and ecology conservation crop as illustrated in Figure 1-1 below due to its physical and chemical properties, and its roots-sucking capacity that are tolerant to metal-rich soils with deficiencies in nutrients such as phosphorus and nitrogen (Nsanganwimana *et al*., 2014). Another study conducted by Alexander (1989) on the rehabilitation of tin mine waste using *Eucalyptus* trees indicated that the extent of the mined soil redevelopment depends on the species being planted. Some species have the ability to improve both nutrient and physical soil conditions in the top soil, while other species caused an increase in soil acidity and reduction in base content. Studies such as these can be used to gain a baseline understanding and guidance in investigating and comparing the ability of bamboo to develop on rehabilitated asbestos mine sites.

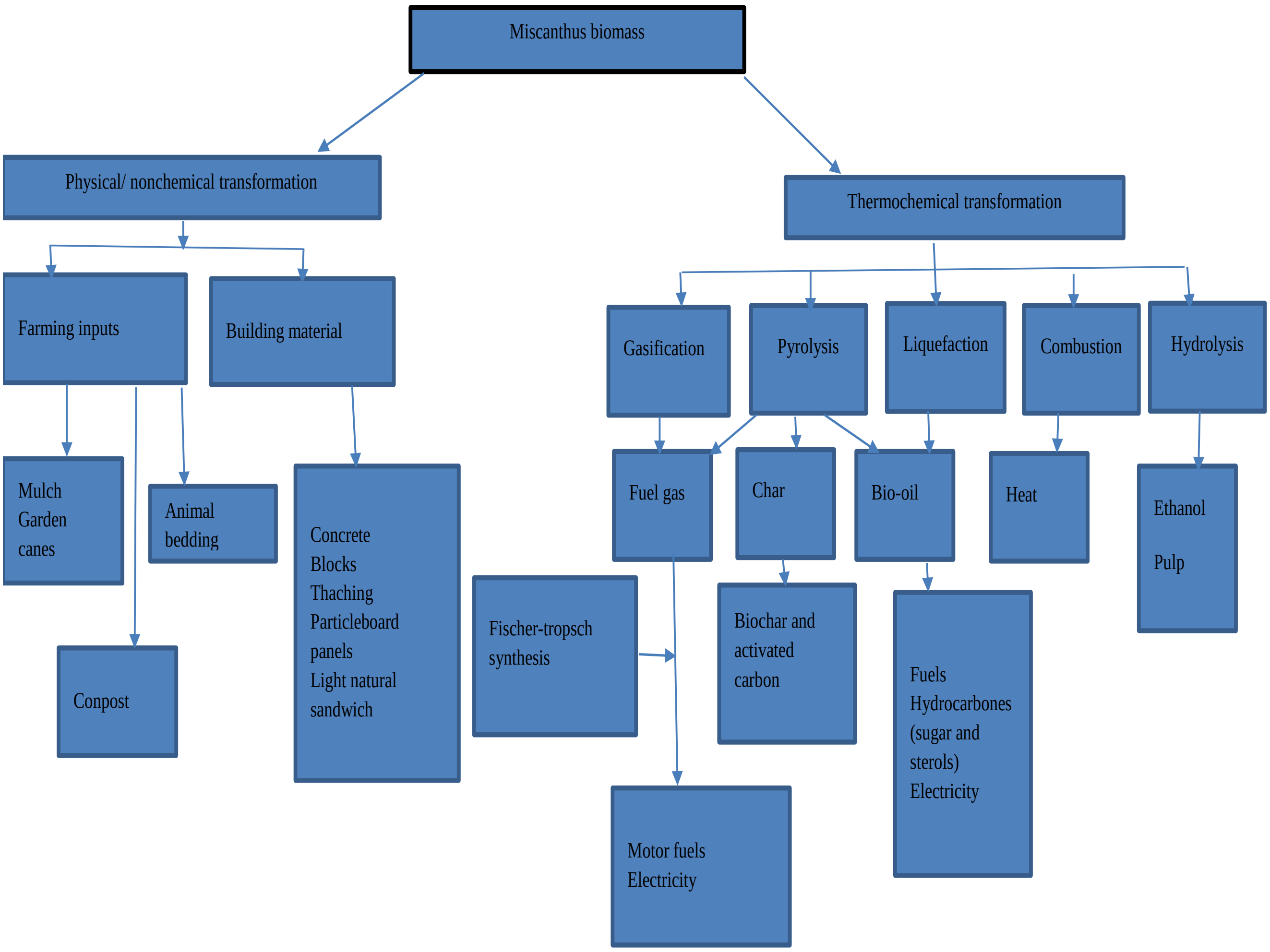

Figure 1-1: *Miscanthus* process pathway for energy production and non-energy product

1.5.1 Bamboo Growth on Mine Waste Materials

The solid bamboo (*Dendrocalamus strictus)*, a perennial woody tropical grass, is a constituent of native dry tropical forests (Tomar, 1963; Singh and Singh, 1991a). Singh and Singh(1999) define the bamboo as a quick-growing and hardy species occurring on a wide range of soil conditions with particularly luxuriant growth and have the following advantages; low ash, low alkali index, high heat value and low moisture content and its disadvantages are that it cannot be mechanically harvested, expensive to establish and its pulp paper quality is lower than that of wood. However overall disadvantaegs are way less than the overall advanatges especially in rural economy. The growth medium includes porous, coarse-grained dry soil with low moisture-retaining capacity and well-drained, sandy loam soils overlying boulders on hillsides with optimum pH of 5.5-7.6 (Yadav, 1963). Singh *et al*. (1999) concluded in their investigation that the *Dendrocalumus strictus* planted on mine wasteland attained similar biomass, but higher net production levels compared to that of native dry forest within a short time. The results indicated that for only 14% biomass, foliage contributed 36% ecosystem function, thus resulting in heavy deposition of organic matter on the soil surface (Singh *et al.,* 1999).

1.6 Rainfall and Bamboo plantation in South Africa

South Africa is a relatively dry country, with an average annual rainfall of 464 mm compared to the world average of 860 mm, but large and unpredictable variations are common (Gandure,Walker and Botha, 2013). While the Western Cape Province Province gets most of its rainfall in winter, the rest of the country ’s provinces get their rainfall in summer between October and February. The average monthly temperature and rainfall patterns vary considerably between winter and summer seasons. In winter, South Africa normally experiences between May and August rainfall and temperature averages of about 25-50 mm and 10-15°C, respectively according to Figure 1-2 below. Rainfall and temperature increase significantly to ranges between 40 and 100 mm and 15 and 30°C, respectively in summer.

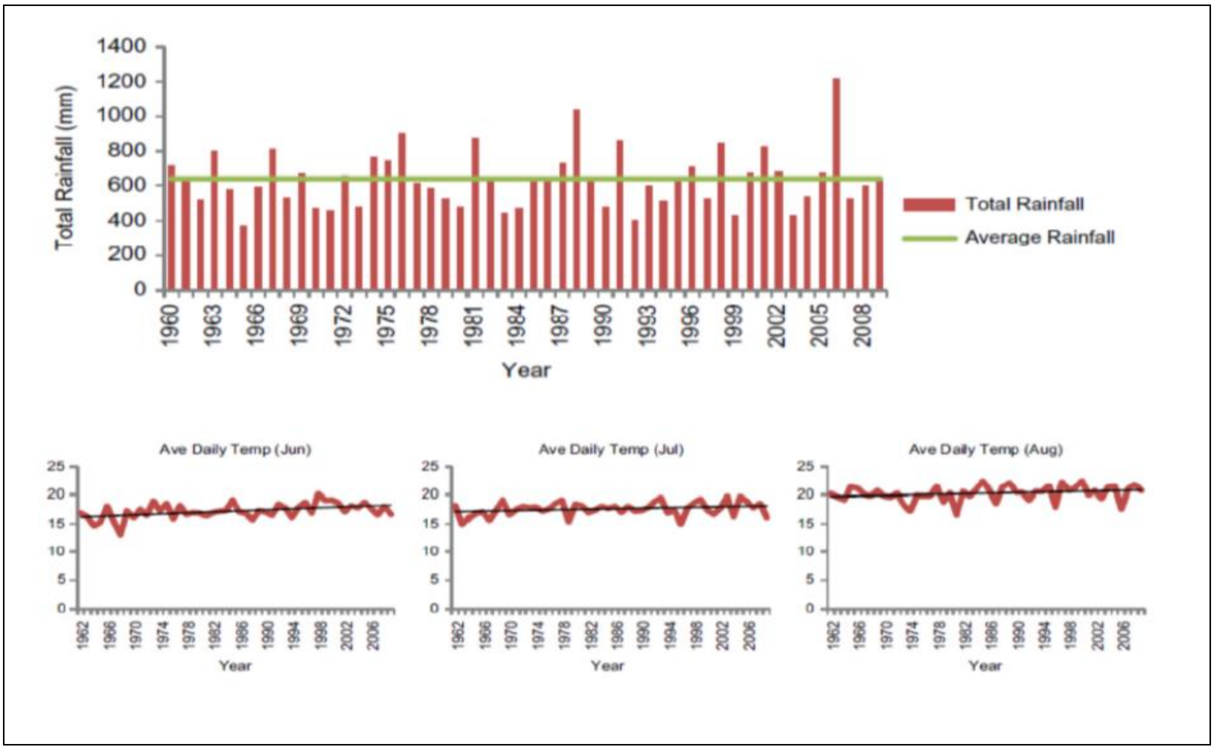

Figure 1-2: Typical South African annual rainfall and temperature pattern (Gandure *et al*., 2013)

South Africa has a rich and diverse natural environment. It has a vibrant variety of vegetation species and a spectacular range of biodiversity, climate and soil type (Goldbatt, 2013). The country is divided into distinct farming regions with activities ranging from intensive crop production in winter rainfall and higher summer rainfall areas to cattle ranching in the bushveld and sheep farming in the arid region of the country (Goldbatt, 2013). The climate, soil combination leaves only 12% of land mass being productive for agricultural activities, while 66% of the land is suitable for grazing. It would be ideal if the proposed energy crops being planted in the region did not compete with this small 12% of productive land, hence the interest in the report of using mine-degraded land as suitable for planting bamboo as a source of energy crop. Figure 1-3 below presents a number of regions, according to the information provided by Afribam, (2014) on where the planting of bamboo can be successful in South Africa, and those regions include Limpopo, Mpumalanga, KwaZulu-Natal and the Eastern Cape Provinces.

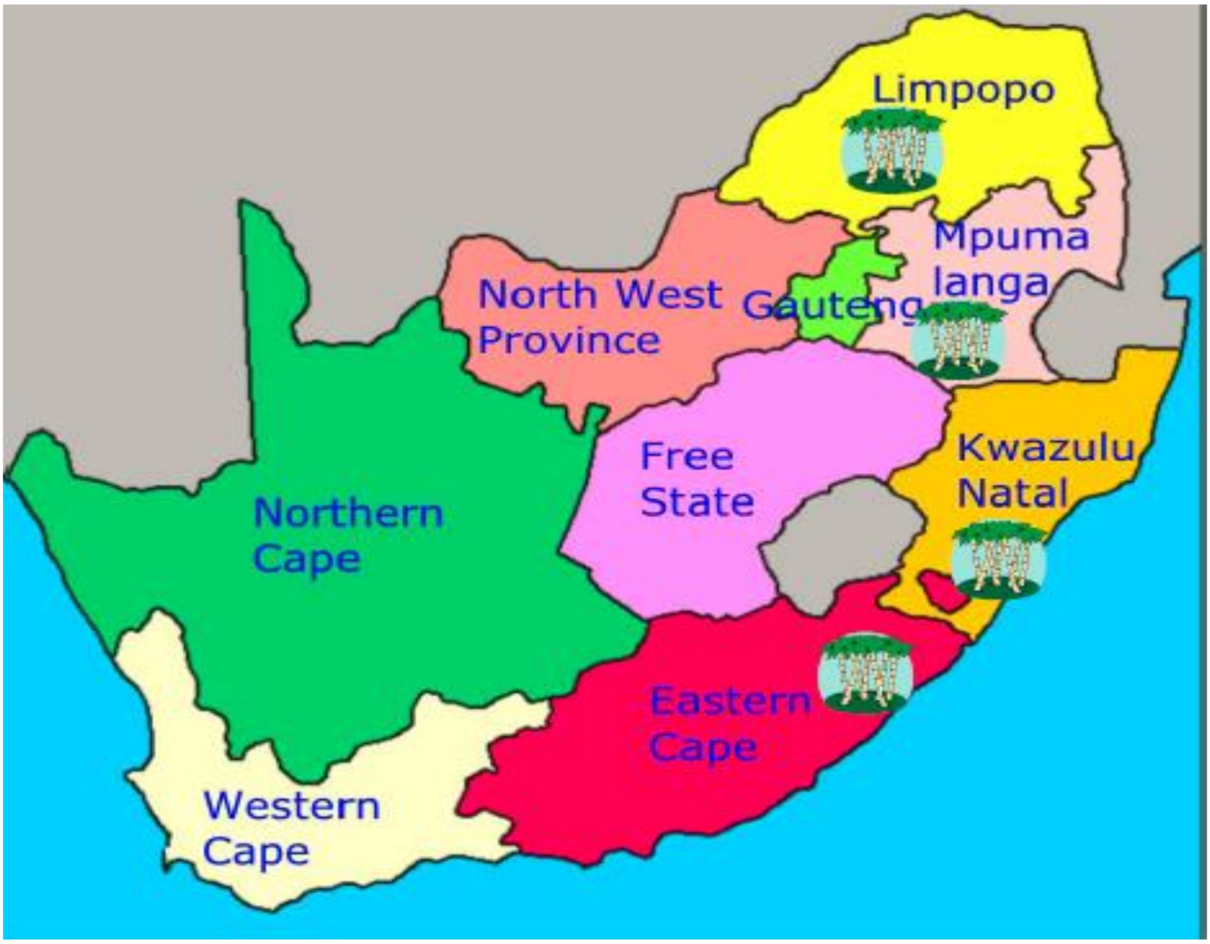

Figure 1-3: The regions of South Africa, where bamboo plantation is deemed successful. (Afribam, 2014)

1.7 Aims and Objectives of the Study

The aims and objectives of this study are three-fold. It is necessary to ascertain whether the data obtained from the bamboo pilot plants from Asia and in South Africa can be used in developing a further economic model for the generation of electricity and planting on derelict and ownerless mines in South Africa. Therefore, the aims and objectives of the study are as follows:

- To determine the regions in South Africa that could be suitable for planting bamboo based on background information obtained from the literature;
- To predict the quantity of a bamboo biomass (ton/ha/yr) expected to be produced on a potential rehabilitated mine site in South Africa that can yield sufficient energy on an economic scale, assuming that the conditions under which these species are being planted are suitable for their growth based on soil, nutrient composition, altitude, temperature, and average rainfall; and
- To develop a techno-economic model that will evaluate the feasibility of using bamboo biomass as a feedstock in a 50kW combustor to generate environmentally clean energy.

1.8 Research Questions

The questions that need to be answered in this research are as follows:

- Is it possible to grow bamboo plants on rehabilitated asbestos mine sites scheduled for rehabilitation?
- Will bamboo, once planted, act as an erosion control measure and agent for replenishing soil organic matter on degraded mine sites?
- Which species, based on available facts in literature, might be successful in terms of climate ,growth, erosion protection, biomass production and use in South Africa?
- Will bamboo-sourced biomass yield sufficient quantity per hectare at an economic scale to be considered as a feedstock in co-generation using a 50kW combustion engine?
- Will planting bamboo promote greener environmental initiatives by improving CO_2 sequestration?
- Are bamboo plantations likely to improve socio-economic conditions for people living around abandoned mine sites?

1.9 Justification for this Research Study

It is hoped that this research will result in the development of a comprehensive, sustainable, long-term rehabilitation plan for abandoned and ownerless asbestos mine sites using bamboo plants. This, in turn, will contribute significantly to finding a sustainable and socio-economic solution to some of the challenges being experienced by rural communities surrounding the abandoned and ownerless asbestos mine sites, as they will have a source of livelihood. Furthermore, an economic evaluation model developed will provide an insight and support to the growing of bamboo plants in a commercial scale, and as a suitable feedstock material for energy generation. Also, the outcome of the research will form the core basis for establishing a bamboo biomass research on a broader basis in South Africa.

1.10 Structure of the Research Report

The research report is organised into five chapters as follows:

- The **first chapter** gives a background on rehabilitation, biomass, and energy issues in South Africa and an indication of why the report has been compiled.
- **Chapter two** provides a literature review on history of asbestos mining in South Africa, legislation, associated environmental impacts, rehabilitation legislation and possible use of bamboo and other biomass on rehabilitation land, bamboo plantation, and energy characteristics of bamboo and other related species by further looking at the economic potential of other biomass and bamboo in particular.
- The **third chapter** describes the methodology used to conduct the study based on literature and some field to derive the economic model used in the study.
- The results presented in **chapter four** are obtained from the model applied based on data from Chapter 3.
- The **fifth chapter** provides a summary of conclusions based on the model results and makes a few recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The previous chapter provided an introduction and background to this study. This chapter will focus on literature pertinent to the study. Asbestos is one of the oldest and most widely used minerals known to humankind. The name 'asbestos' is derived from the Greek word meaning inextinguishable flame, and the Greeks termed this mineral the miracle mineral (Weyers, 2010). The use of asbestos, however, turned out to be one of the most controversial issues surrounding the industrial mineral industry. The carcinogenic nature of asbestos, the lack of knowledge of minimum safety exposure levels of mining companies and the long latency for the development of lung cancer and mesothelioma are the main factors surrounding the controversy regarding asbestos (Virta, 2003).

The mining of asbestos generates vast amounts of residual material that are chemically not different from the parent rock. An important difference is its fineness and its susceptibility to weathering. The residue dumps are unsightly and subject to wind erosion. Re-vegetation of asbestos dumps is not only aesthetically desirable but is also a means of stabilising the material, which, if airborne, is a potentially serious health hazard (Meyer, 1980). The main problems associated with the establishment of vegetation on asbestos tailings are extremely alkaline conditions, low nutrient concentration, such as phosphorus, potassium and calcium, and surface crusting (Hossner and Hons, 1992).

2.2 Geological Occurrence of Asbestos in South Africa

Asbestos is a collective term for six naturally occurring fibrous minerals from the amphibole and serpentine group of rocks. These have been used in the manufacturing of commercial products such as asbestos and cement for many decades. The most important properties of asbestos, which account for its widespread use in a broad range of asbestos-containing products, include high tensile strength, flexibility, resistance to chemical and thermal degradation, high electrical resistance, and resistance to bacterial and fungal attacks. The most common asbestos types are chrysotile $Mg_6\ [(OH)_4\ Si_2O_5]_2$ (white asbestos), which is a fibrous form of serpentinites and the most abundant form; crocidolite $Na_2Fe_5[(OH)Si_4O11]_2$ (blue asbestos); and amosite $MgFe_6[(OH)Si_4O_{11}]_2$ (brown asbestos). Crocidolite and amosite are forms of asbestos minerals belonging to the amphibole group (Hart, 1988).

Asbestos fields occur in various Provinces throughout South Africa. Crocidolite occurs mainly in the North-West, Limpopo and Northern Cape Provinces (Weyers, 2010). The crocidolite fields of the Northern Cape Province stretch over 450 kilometres, from south of the town of Prieska on the Orange River to the Botswana border (Hart, 1988). The geological deposits of crocidolite asbestos occur in cross-fibre seams in the banded ironstones of the Asbestos Hills Formation in the Griquatown Group; they range in thickness from less than 1 mm to approximately 50 mm. The maximum fibre length is about 150 mm (Howling, 1937; Hart, 1988). Amosite asbestos deposits are found nearly entirely in the Mpumalanga and Limpopo Provinces. The amosite asbestos deposits occupy portions of the Polokwane and Letaba districts, extending from Chuniespoort in the west to the Steelpoort River in the east, a distance of approximately 90 km (Weyers, 2010). In this region, the asbestos is confined to the banded ironstone of the Penge formation of the Chuniespoort Group (Hart, 1988). There are many deposits of chrysotile in the Limpopo and KwaZulu-Natal Provinces. The most important chrysotile deposits are those located in the Barberton area in Mpumalanga Province, where the chrysotile asbestos bodies are hosted in ultramafic intrusion within the Swartkoppies Formation, which forms part of the Onverwacht Group of rocks (Hart, 1988; McCullon, 2003).

2.3 History of Asbestos Mining in South Africa

Asbestos mining in South Africa began in earnest in the 1930s, and this attracted a multitude of mining companies throughout the subsequent decades to the 1980s and 1990s. South Africa is the only country in the world that has reserves of, and produced all three principal varieties of asbestos, namely, chrysotile, amosite and crocidolite asbestos (Hart, 1988). South Africa together with Canada and Zimbabwe are the most important asbestos-producing countries in the former British Empire. From 1950 through to the mid-1980s, South Africa was the second most important producer of asbestos. After World War II, production increased dramatically, aided by the worldwide demand for asbestos as a result of reconstruction activities in Europe and other growing economies in Asia.

The number of mills in South Africa increased rapidly, setting aside increased fibre production. Mining increased from 41 500 tons per annum in 1948 to its peak of 380 000 tons per annum in 1977 (Virta, 2003). At its peak in the 1970s, the South African asbestos mining industry employed 20,000 asbestos mine workers (Coombes, 2002). Two international mining groups, the Griqualand Exploration & Finance Company (Gefco) and British-owned Cape Asbestos SA, were the major companies involved in the mining of asbestos in South Africa from the 1940s to the late 1990s. By 1981, the foreign companies had withdrawn from active mining in South Africa, and a series of mergers and acquisitions had reduced the major producers to only two, along with Msauli Asbes, which was later called Hanova (Hart, 1988).

As the awareness of asbestos-related health impacts increased, sales started declining, indicating that production was outpacing demand. South African producers as well as the then Department of Mines dismissed medical evidence about the dangers of asbestos to human. The two organizations blamed Canadian and Russian interests for seeking to have chrysotile mined in SA phased out of the market due to the non-competitive amosite and crocidolite (Virta, 2003 and McCulloch, 2003). After asbestos production peaked in 1977 world wide , production declined rapidly to 135 000 tons in 1987, 50 000 tons in 1997, and 6 220 tons in 2003 (Virta, 2003). The south Africa's asbestos mines began closing down towards the end of the 1970s as a result of the declining international demand for the mineral. Crocidolite asbestos mining stopped in 1989, whereas amosite production and mining stopped in 1992. The last chrysotile mines (Kaapsehoop and Msauli) ceased mining operations in 2001. There was a stockpile of chrysotile asbestos fibre at the Msauli mine near Barberton. These stockpiles were estimated to have been sold off by September 2003. During this time, Hanova Mines Pty Ltd employed approximately 20 people who worked on closing down and rehabilitating the mines (Weyers, 2010).

2.4 Asbestos Mining Legislation

Before 1956, companies that mined asbestos in South Africa were not bound by law to conserve the environment. The first piece of legislation that was applicable to the mining of asbestos was introduced in 1976 under the Atmospheric Pollution Prevention Act (Act No. 45 of 1965), where asbestos-producing areas were declared as dust pollution sites. The Minerals Act (Act No. 50 of 1991) was the first piece of legislation that explicitly stated that mining companies were liable for the rehabilitation of the environment that would have been affected by their mining operations. Section 12 of the Minerals Act of 1991 states that the holder of a mining licence over a piece of land is liable for complying with the relevant provisions of the Act until a certificate has been issued to the effect that the said provisions have been complied with (Nel, 2006). Current legislation governing mining companies in South Africa impose a clear obligation on mining companies to prevent environmental damage and clearly define their mine rehabilitation and closure liabilities. Three principal pieces of legislation, namely, the South African Constitution Act of 1996, the National Environmental Management Act of 2008 and the Mineral and Petroleum Resources Development Act (MPRDA Act No 28 of 2002), as well as the Amendment Bill of 2013 clearly outline the environmental obligations of mining companies.

The South African Constitution states that every citizen has the right to an environment that is not harmful to health and well-being, and the Bill of Rights enables members of the public to enforce that right. Over and above that, Section 24 (b) of the Constitution tasks national, provincial and local government with the responsibility to ensure that the environment is protected in the interests of the public (Constitution of the Republic of South Africa, 1996). The Constitution defines and bestows the environmental rights of citizens and sets out the enforcement of these rights and allocation of environmental stewardship on behalf of the citizens to the different levels of government. While Provinces set the standards of environmental control within a national framework, local authorities implement and administer the legislation in areas under their jurisdiction, supplementing it with by-laws where necessary.

The National Environment Management Act (NEMA) of 2008, lays out the principles for environmental protection and waste management in the country. These include avoidance or minimization of waste, waste reduction, reuse, recycling, and proper disposal, and the 'polluter pays' and 'cradle to grave' principles are emphasized. With respect to mining, NEMA empowers the Minister of Mineral Resourcesto align and enforce environmental management and regulations for the exploration, mining and production of minerals in the country. Under the MPRDA of 2002, the DMR regulates environmental management in prospecting, mining, and production of minerals. The MPRDA of 2002 states that mining companies must conduct environmental impact assessment studies before the commencement of mining activities and that they have environmental rehabilitation obligations during and after the useful life of the mine. In terms of the MPRDA, a mineral rights holder must give effect to integrate environmental management objectives in their operations. The holder of mining rights is obliged to consider, investigate, assess and communicate the effects of the environmental impact of a mining activity to the DMR. All adverse environmental impacts must be managed and mitigated. As far as reasonably possible, the environment must be rehabilitated after the operation to its natural state or a land use conforming to accepted principles of sustainable development.

In 2001, South Africa banned asbestos mining, and regulations were put in place to prohibit the use, manufacture, import and export of asbestos and asbestos-containing materials (Naidoo, 2008). In 2004, the South African Government announced its intention to phase out the use of asbestos by 2009. This announcement caused turmoil in neighbouring Zimbabwe, which at the time was still a major exporter of chrysotile. From 2004 to 2006, Zimbabwe lobbied for a change of heart for the ban of asbestos proposals, by indicating that chrysotile fibre has a different structure and chemical composition, and that it is not a health or environmental risk (Kazan-Allen, 2006). The leading asbestos manufacturer in Zimbabwe, Turnall Fibre Cement, believed that the ban would have a significant impact on its export earnings, with exports to South Africa having earned the company R22 million in 2007 (Naidoo, 2008).

The then Department of Environmental Affairs and Tourism (DEAT) gazetted asbestos banning regulations on 28 March 2008. The legislation prohibits the import or export of asbestos or asbestos-containing materials, excluding material in transit through the country, and prohibits the acquisition, processing or repackaging of asbestos and the manufacturing or distribution of asbestos (Holman, 2008). The prohibition was focused on the effort to stop the use of asbestos, but it did not resolve the enormous environmental contamination resulting from asbestos mining operations, nor the problem of existing asbestos still found all over South Africa (Holman, 2008). As part of the Cape Plc Ltd case in 2001, certain conditions had to be satisfied before any money could be distributed. One of these conditions was that the South African Government should agree not to hold Cape Plc Ltd liable for the clean-up of former sites. Together with the implementation of the MPRDA (Act 28 of 2002), the South African Government (specifically the DME) became responsible for the clean-up of all abandoned asbestos mines (Weyers, 2010).

2.5 Environmental Impacts of Mining

The mining of non-renewable Mineral Resourceshas various known impacts on the natural environment throughout the mining life cycle. The mining process generally has four stages of development, and each stage has an environmental management challenges associated with its activities (see Table 2-1). In South Africa, there is growing awareness of the environmental legacy of mining activities. While awareness of the environmental impacts has increased significantly in recent years, the activities of mining companies are not closely monitored with a view to minimizing adverse environmental consequences. Legislation and technology are the key determinants of the environmental footprint of mining activities in a particular area (Fourie and Brent, 2006). Table 2-1 below summarizes the environmental impacts of mining at each stage of the value chain.

Table 2-1: Environmental impacts of four stages of mining (Fourie *et al*., 2006)

Development Stage	Activity Phase	Environmental issues subject to mitigation/prevention measures
Exploration	Airborne and ground-based geo-chemical, transport, bulk sampling surveys	Land alienation from protection options, camp garbage
	Prospecting, claim stacking, line cutting, stripping	Trail and trenching erosion, access-related over harvesting and fishing
	Geophysical, drilling and trenching, road/trail building and/or helicopter, transport, bulk sampling	Habitat disruption, noise pollution, and acid mine drainage
Mining and Milling	Environmental impact assessment, mine design and construction	Wildlife and fisheries habitat loss, changes in local water balance
	Stripping/storing of “overburden” of soil and vegetation, ore extraction	Sedimentation, containment of toxins in tailings ponds or leaching solutions
	Crushing/grinding of ore, flotation or chemical concentration of ore	Tailings ponds or leaching pad stability failure
	Mine and surface water, treatment, storage, waste rock and tailings	Potential acid generation from waste rock and pit walls, heavy metal leaching from acid mine drainage, cyanide solution contaminant at heap leach operation, wind-borne dust
Smelting and refining	Processing of mineral concentrate by heat or electro-chemical processes	Sulphur dioxide emissions contribute to acid rain, toxic chemical (e.g. ammonia, sulphuric acid) and high energy process requirement
Mine closure	Re-contouring of pit walls, waste dumps, covering of reactive tailings dumps	Seepage of toxic solutions into ground and surface water
	Decommissioning of roads, dismantling of buildings, re-seeding/planting of disturbed areas	Acid mine drainage, wildlife, and fisheries habitat loss, re-vegetation failure
	Ongoing monitoring and possible water	Wind-borne dust, slope and tailings

	quality treatment	impoundment failure

2.6 Rehabilitation of Mines

Mining waste usually includes waste rock and tailings on land surfaces which often pose highly stressful conditions for rehabilitation (Li, 2006). Abandoned mine tailings have highly diverse physical, chemical and ecological conditions (Weyers, 2010). The tailings are normally variable in physical composition with depth, low organic matter and the lack of essential plant nutrients which complicate the establishment of vegetation (Hossners and Hons, 1992). The aim of rehabilitation of sites disturbed by mining activities is to restore the disturbed site to their former state or to a sustainable, usable condition through emphasising the reparation of ecosystem processes, products, and services (SER, 2004). The long-term objectives of rehabilitation can vary from simply converting an area that was previously affected by mining activities to a safe and sustainable condition or to restoring the pre-mining conditions as closely as possible and support the future sustainability of the site.

Internationally, there are three schools of thought to the objectives of rehabilitation. An investigation conducted by the Centre for Sustainability in Mining and Industry (CSMI, 2010) at the University of the Witwatersrand summarises the three objectives as follows:

- "What the affected community wants, the affected community gets" – the key focus in this proposition is on providing the end product requested by the affected communities rather than on the previous status quo.
- "Restoration of previous land use capability" – this is the original thought process in the South African rehabilitation context because mining often occurs on land that has got high agricultural potential.
- "No net loss of biodiversity" – there must be no loss of biodiversity during the rehabilitation process. Rehabilitation of a derelict mine must restore the biodiversity of the site to its natural state.

In the South African context, the rehabilitation objectives usually contain elements of all three approaches (Weyers, 2010). Rehabilitation objectives should align with the national and regional Integrated Development Plans (IDPs), which may or may not match the local community wishes (Coaltech, 2007). Fourie *et al* (2006) maintains that the rehabilitation of a mine should ideally be planned before any mining commences, using the data provided by exploration. Especially the information should include physical, chemical, hydrological, and geotechnical properties of ore, gangue and country rocks, and it should be utilized to prepare the environmental management program (EMP) for the mine site (Taylor, 2004). Fourie and Brent (2006) further notes that an EMP is also necessary for operational mines to ensure that the best results are achieved and that community and regulatory authorities are involved and satisfied with the EMP in place. Figure 2-1 below summarises the life cycle of a mine.

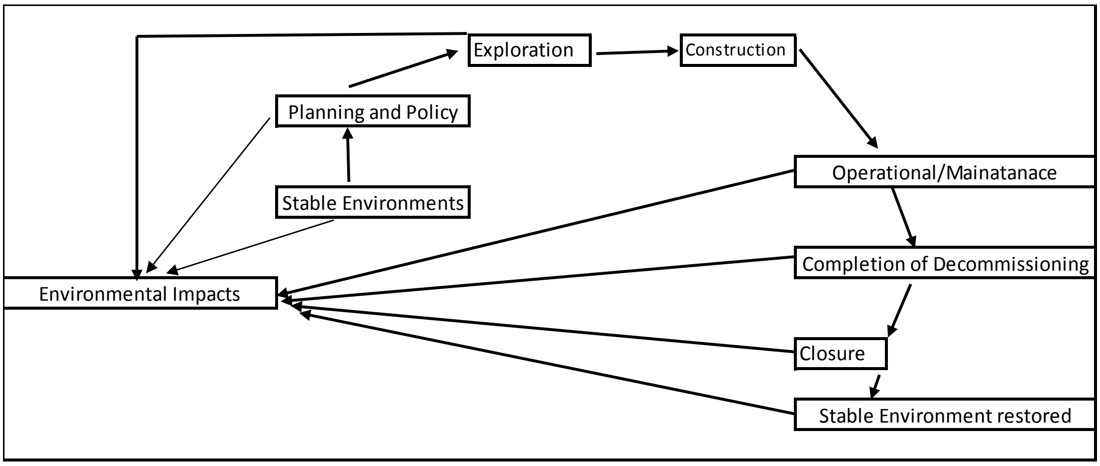

Figure 2-1: A general life cycle of a mine (Ressen, 2003)

Taylor (2004) considered the following factors to be useful for the successful implementation of a mine rehabilitation programme:

- physical and chemical stability of mine waste dumps,
- maintenance of water quality,
- safe disposal of infrastructure,
- development of sustainable ecosystems, and
- meeting community expectation.

Most of South Africa’s current mines have been in operation for more than 50 years. When mining started in South Africa in the late 1870s, the planning and mining methods that were used did not take into account the adverse ecological impacts of mining on the environment. The design of rehabilitation programmes requires a holistic view of the full cycle of mining operations, with mine rehabilitation and closure plans being an integral part of all mining activities. Maximising planning reduces site disturbance and ensures that a material such as waste rock is close to its final location (Fourie *et al*.2006). According to Van Renssen (2003), the historical mine rehabilitation model that was developed by the then DME did not take into consideration the re-vegetation of the mine site to be rehabilitated. Fourie *et al* (2006) revised the aforementioned framework and developed the current model of rehabilitation that integrates best practices of project management, according to the Project Management Body of Knowledge (PMBOK) principles with DMR. Figure 2-2 below illustrates the mine closure model based on a coal case study that incorporates PMBOK principles.

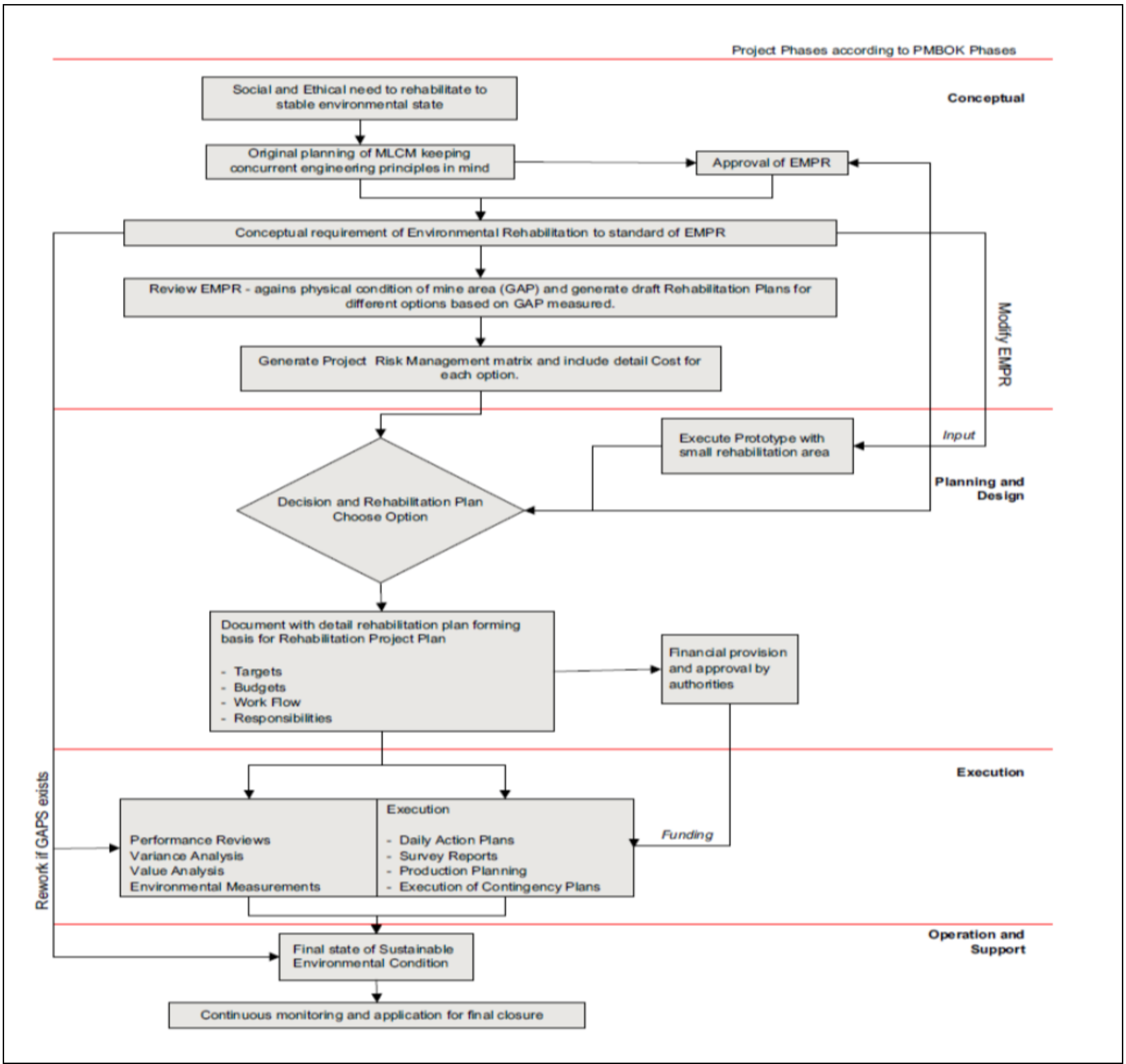

Figure 2-2: Mine closure model (Fourie *et al*, 2006)

According to Fourie *et al* (2006), the mine closure model aligns the focus of South African Government with those of mining companies towards preservation of the environment as specified in the environmental management programme (EMPR) at the beginning of mining activities. In terms of the MPRDA of 2002, South African mining companies should accept the long-term liabilities of their actions on the environment. Fourie *et al* (2006) maintain that the mine closure model can be used as an effective and transparent tool for mine rehabilitation programmes.

2.6.1 Factors Influencing Rehabilitation of Asbestos Tailings Dumps

Derelict asbestos mine sites are nutritionally impoverished habitats characterised by low nitrogen mineralisation rates, low phosphate availability, low soil organic matter, poor soil structure, compacted subsoil, poor drainage, and low water holding capacity (Singh, Raghubanshi and Singh, 2004). The possible post-mining land uses of land disturbed by mining are influenced by characteristics of the environment in which the mine is sited, the nature of the mining process, and social considerations (Mulligan, 1997). The key question facing land managers attempting to remediate or restore degraded land is how to measure the success or failure of rehabilitation efforts on a particular site or landscape (Harris, 2003).

One of the main objectives for rehabilitation of any mine is the re-establishment of vegetation, which appears to be the answer to achieving rehabilitation success on mine discard sites (Weyers, 2010). However, re-establishment of the ecosystem function in post-mining landscape calls for a holistic approach to rehabilitation (Claassens, 2007). There are several potential soil limitations to plant establishment and growth on asbestos tailings. Each site must be evaluated separately to identify adverse substrate characteristics prior to preparation for re-vegetation. At many asbestos mine sites, there is evidence of two or more adverse factors, and it is often interaction of these factors that determines the successful rehabilitation as measured by plant establishment and vegetative growth (Hossner and Hons, 1992). Grasses and legumes are the most effective plant types for controlling erosion in the early stage of reclamation. Trees and shrubs have an advantage of providing a permanent cover on disturbed areas with little or no additional aftercare or maintenance (Singh *et al*., 2004). Because of deep roots, trees are able to loosen compacted soil to greater depths than grasses. Tree plantations are nutrient and carbon sinks, a condition that leads to the re-establishment of soil fertility and forest conditions within which native species can prosper (Singh *et al*., 2004).

Trees can improve soils through numerous processes, including maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below the reach of the roots of understory herbaceous vegetation, increased water infiltration and storage, reduced loss of nutrients by erosion and leaching, improved soil physical properties, reduced soil acidity, and improved soil biological activity (Singh *et al*., 2004). However, the impacts of trees on soil fertility depend on their nutrient cycling characteristics such as litter chemistry and decomposition (Singh *et al*., 2004). Some plantation species exhibit high nutrient use efficiency and maybe more effective nutrient sinks than other species (Singh *et al*., 2004). The study of soil characteristics in restoration remains important and is one of the primary agents in determining vegetation development (Singh *et al*., 2004).

2.6.2 Use of Bamboo Plants in the Rehabilitation of Asbestos Tailings Dumps

Although bamboo plants have been used widely across many regions in the world in rehabilitating deserted mine sites, there are difficulties in convincing South African mining companies to plant bamboo when re-vegetating old mining sites. Mintek, a state owned mineral processing and metallurgical research institute was tasked by the Department of Mineral Resources(DMR) to undertake a study on abandoned mine sites in order to evaluate the feasibility of rehabilitating derelict and ownerless asbestos mines using bamboo plants in 2011. The major findings of the study were that bamboo plants have considerable economic potential as well as significant value in the rehabilitation of waste mine land (Landu and Mashai, 2011). Bamboo was also found to be a very hardy plant with low ash, low alkali index, low moisture content, high heat value and surviving under the harshest of climatic conditions. It is also a perennial plant; once established, there is no need for replanting, as harvested culms are replaced by new shoots emerging from the underground rhizome system. This aspect enables sustainable, regular harvesting of culms and thus stable income for producers, with only low investments. If used wisely, such plantations and their products could also be used to uplift the socio-economic condition of the local communities living on or close to abandoned mines by the development of microenterprises sourced from bamboo materials (Landu and Mashai, 2011).

Another internal report from Mintek, written in 2011, recommended Penge asbestos mine in Limpopo Province as a suitable test site for planting bamboo. This study was abandoned based on information from the literature and some academics that the bamboo plant is invasive and that it would require considerable quantities of water for irrigation during the initial phase of its growth (Landu and Mashai, 2011), but this fact is yet to be tested on the species of bamboo in South Africa.

Other alternative species such as *Euphoria tirucalli* and mixed of seed grasses like *Antephora pubeseens; Cenchrus cilliaris; Cynodon dactylon; Digitaria criantha; Enneapogon cenchroides; Eragrostis curvula; Eragrotis teff; Heteropogon contorius* and *Pogonarthria squarrosa* as discussed in the introduction and many others used in coal mine spoil rehabilitation elsewhere in India on dry land and on tropical land which includes; *Albizia procecera*, A*lebbeck* and *Tectona grandis* as discssued by Singh *et al*., 2004.

Five other exotic species like *Acacia auriculiformis*, *Casuarine equisetifolia*, J.R and Forst (Beefwood tree), *Cassia siamea* lamk (Yellow cassia), *Eucalyptus hybrid* ,Pryor and Johnson (White gum) and *Gravellina pteridifolia* R.Br. (Silver oak) planted in the forest department of Madhya Pradesh in India and looked by Dutta and Agrawal in 2003 for application on coal mine spoil.

Although all these species above have shown potential to be grown on mine spoil and offer competive advantage in controlling erosion on mine rehabilitation land especially coal mines, they do not offer added benefits of being harvested as energy feedstock crops as compared to bamboo which offer such economic benefits once processed further based on suitable technology.

2.7 Introduction to Bamboo Plants

Bamboo is a natural occurring form of vegetation which grows abundantly in most tropical countries throughout the world. Over 1200 bamboo species have been identified globally (Wang and Shen, 1987 and Lobovikov,Paudel,Piazza,Ren and Wu, 2007). India was found to have the largest bamboo resource, as seen in Figure 2-3a below. Bamboo plants belong to the family of grasses (Poaceae), such as rice, wheat and sugar cane. It can be classified as ‘running’ (monopodial) bamboos and ‘clumping’ (sympodial) bamboos, with the latter dominating tropical regions and growing in clumps (Figures 2-3a and 2-3b). Bamboo plants are among the most versatile and widely used plants in the history of humankind, with applications ranging from edible shoots to soil protection and construction. Bamboo is considered a composite material because it consists of cellulose fibres embedded in a lignin matrix. Cellulose fibres are aligned along the length of the bamboo, providing maximum tensile flexural strength and rigidity in that direction (Lakkad and Patel, 1980). In modern times, they are widely used in the manufacturing of household products. Advances in technology and increasing demand have resulted in bamboo plants been widely used for a variety of industrial applications.

In Asian countries, bamboo plants are used for household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts and chairs. They are also widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses, rafters, and purlins. Additionally, they are used in construction as structural materials for bridges, water transportation facilities and skyscraper scaffoldings. About 35 species are now used as raw materials for the pulp and paper industry. Massive plantations of bamboo provide an increasingly important source of raw material for the pulp and paper industry in China (Hammett,Youngs ,Sun and Chandra, 2001).

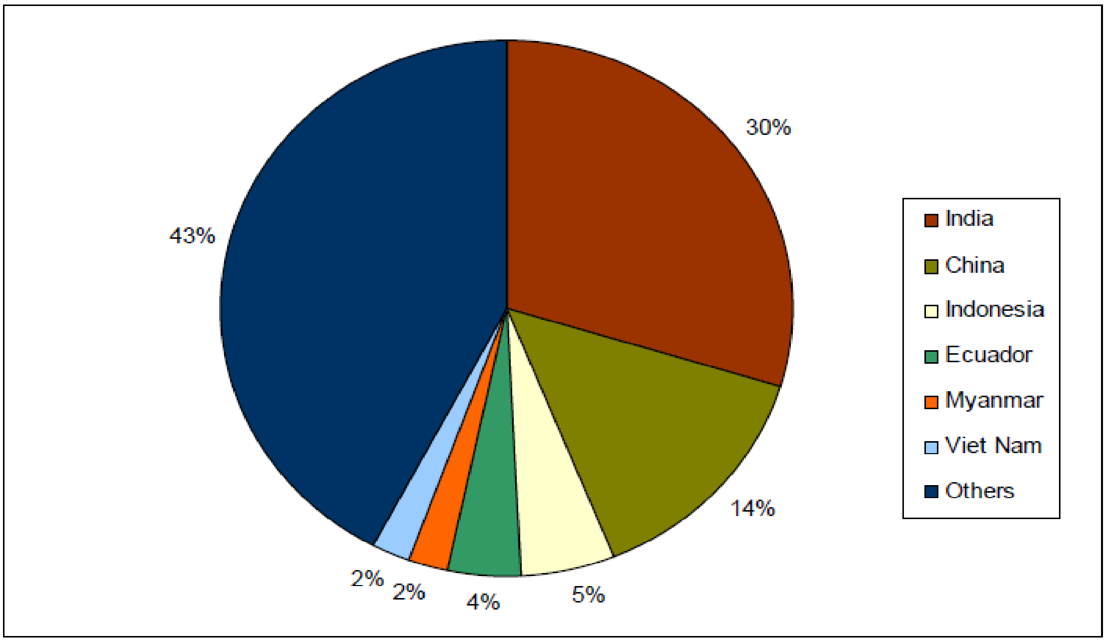

Figure 2-3a: Countries with the largest bamboo resource (Lobovikov *et al.*, 2007)

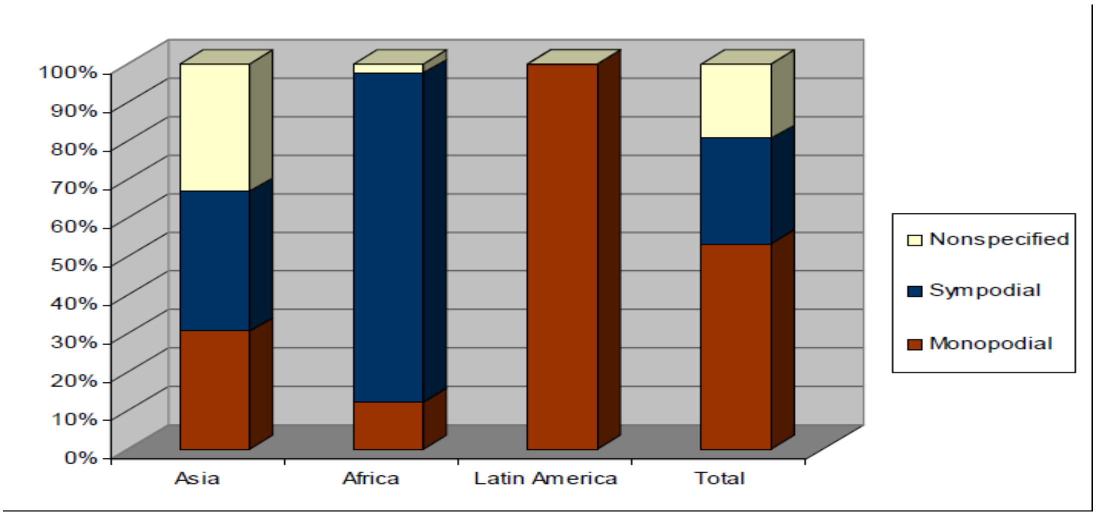

Figure 2-3b: Composition of bamboo type by continent (Lobovikov *et al.*, 2007)

2.7.1 Taxonomy of Bamboo Plants

Bamboo plants are a perennial, woody grass belonging to the group Angiosperms in the order Monocotyledon (Chapman, 1996 and Abd.Latif *et al.*, 1990). The grass family Poaceae or Gramineae can be divided into one small subfamily, *Centothecoideae*, and five large subfamilies: *Arundinoideae, Pooideae, Chloridodeae, Panicoideae and Bambusoideae*. In distinction to its name, bamboos are classified under the subfamily *Bambusoideae* (Chapman, 1996). Bamboo plants encompass more than 1 250 species, most of which are relatively fast-growing, attaining maturity within five years, but flowering infrequently (Scurlock ,Dayton and Hames, 2000). Most of the bamboo species require a warm climate, abundant moisture, and productive soil, though some grow in reasonably cold weather of below –20°C (Wang and Shen, 1987). Grosser and Liese (1997) maintain that bamboo plants grow particularly well in the tropics and subtropics, but some species thrive in the temperate climate of Japan, China, Chile and the USA.

Bamboos are extremely diverse plants that easily adapt to different climatic and soil conditions. Dwarf bamboo species grow to only a few centimetres (cm), while medium-sized bamboo species may reach a few metres (m), and giant bamboo species grow to about 30 m, with a diameter of up to 30 cm . The plant can survive and recover after severe droughts, floods, freezing, extreme heat catastrophes and damage. Young bamboo shoots were the first sign of new plant life after the nuclear bombing of Hiroshima and Nagasaki (FAO, 2005).

Bamboos can also adapt to various types of habitat. They grow in the plains, in hilly and high-altitude mountainous regions, and in most kinds of soils, except alkaline soils, desert and marsh environments (Wang and Shen, 1987). Bamboo plants could grow from sea level to as high as 3 000 metres. They grow well on drained sandy to clay loom soil or from underlying rocks with a pH of 5.0 to 6.5 (FAO, 2005).

2.7.2 Morphology and Growth

A bamboo plant is divided into two major parts: the rhizome and the culm. The rhizome is the underground part of the stem and is mostly sympodial or to a much lesser degree, monopodial. Above the ground portion of the stem is called the culm. It is that portion of the bamboo tree that contains most of the woody material that can be converted into biomass material as a source of fuel for energy production. Most bamboo plant culms are cylindrical and hollow, with diameters ranging from 6.25 to 305 mm, and heights range from 0.3 m to 37 m (Lee,Xuesong and Perry, 1994). The plant has no bark, but it has a hard, smooth outer skin due to the presence of silica (Tewari, 1992). The culm is complemented by a branching system, sheath, foliage leaves, flowering parts, fruits and seedlings. Nearly all bamboos can adapt to varying environments, most require relatively warm and humid conditions, e.g. mean annual temperature of at least 20 °C and annual precipitation of at least 1 500 mm (Nath,Das and Das, 2004). Sprouting buds appear as swellings on the side of the underground rhizomes, which generally occupy the top 30-50 cm of the soil. These may spread laterally for tens of metres. With the onset of warm spring weather, the bud lengthens and develops into a compact upright shoot, which forms a sharp point and penetrates the ground surface. After emergence, there is little radial growth of the shoot, with "growth" taking the form of massive elongation of internodes, as much as 0.5 m per week in the case of tall bamboos, until the shoot is approximately the same height as the rest of the stand (El Bassam, 1998).

2.7.3 Propagation Methods for Bamboo Plants

Bamboo plants can propagate from three main morphological parts: the aerial part (the culm) and two underground parts (the rhizome and root). According to Rao ,Ramanatha and William,1998 because of the scarcity of seeds, a bamboo plant is generally propagated by vegetative methods and these include clump division, offsets, rhizome, whole culm cutting, layering, culm-segment cutting, branch cutting, and macro-proliferation. All these methods have been studied in different countries and each country has methods suitable for its own species.

Clump division is the traditional and perhaps the most generally prevalent method of vegetati ve propagation (McClure, 1966). Clump divisions are generally performed in two ways: offset and rhizome planting. In offset planting, parts of the culm are used to propagate the plant, while in rhizome planting the roots of the bamboo plant are used to propagate the plant. Kurz (1976) described the culm cutting method as taking whole culms with their roots and burying them lengthwise into the ground. Culm segments of the bamboo plants containing two or three nodes bearing healthy buds or branches have been used for propagation (McClure, 1966). In the layering method, the bamboo plant is bent down into the ground or a shallow trench. White (1947) reported that it was possible to propagate some bamboo species such as *Gigantochloa verticillata* and *Sinocalamus oldhami* using branch cuttings. Delgado (1949) and McClure and Durand (1951) also propagated bamboos by using branch cuttings, but with poor rooting percentages. In the macro-proliferation method, bamboo plants are propagated using tillers, rhizomes, culms and seeds. Like many other kinds of grass, bamboo plants have the inherent capacity to propagate and reproduce themselves vegetatively, probably due to their long inter-seeding period. By utilising this approach, an interesting technique has been developed by Banik (1987a) for multiplication of a seedling through the rhizome separation method. He termed the technique macro-proliferation of seedlings.

2.7.4 Weakness of Conventional Propagation Methods

The traditional rhizome, offset and culm and branch-cutting methods are applicable only in cultivating few clumps, particularly within a small holding and cannot be replicated on a commercial scale. Some of the limitations of the conventional propagating methods are as follows:

- The conventional propagation methods are labour intensive and expensive if they are done on a commercial scale.
- Offsets, branch cuttings, and rhizomes are bulky and heavy (4-30 kg per propagule) and, as a result, difficult to handle and transport.
- The survival success rate in most species ranges between 5 and 50%.

- Availability of propagules per clump is limited, as only young (one to two years old) culms can be used as propagules. Not more than 30-50% young culms should be collected from a clump; otherwise, it would lose its regeneration capability.
- McClure (1966) maintains that the meagre development of roots, decay of rhizomes, and slowness of rhizome buds to break dormancy are some of the problems that can be experienced when propagating bamboo plants on a commercial scale.

2.7.5 Harvesting Techniques for Bamboo Plants

Farrelly (1984) attempted to explain the basic cultivation and harvesting methods of bamboo plants, using the systematic harvesting techniques, which was not well known. When bamboo plants are harvested, there is no consideration for their final intended usage, and the high initial moisture content of the plants may easily cause splitting. The uncertainty of age of the harvested bamboo will create challenges in the processing and utilisation of the plants. Some of the factors that should be taken into consideration for the improvement of the harvesting technique are age, desired quality, and the quality of feedstock required by end users. Farrelly (1984) asserts that the best time to harvest bamboo plants is after the rainy season when the bamboo sap is low. Ideally, bamboo plants should be harvested when they are between three and five years old, and this should not be done during the shooting season. The harvesting of bamboo plants older than five years is difficult because the inner culm wall is harder to cut and is less impermeable to boric acid/borax treatment solution.

2.7.6 Environmental Benefits of Bamboo Cultivation

As a typical forest type in subtropical and tropical areas, bamboo forests play a pivotal role due to their biological characteristics and growth habits. This plant form is not only an ideal economic plant for utilisation in many ways, but it also has a positive effect on many environmental issues. Bamboos have displayed positive ecological characteristics on soil erosion control, water conservation, land rehabilitation and carbon sequestration (Zhou *et al.,* 2005). Song *et al.* (2011) also reviewed the ecological function in Chinese bamboo forests, including carbon sequestration, water and soil conservation, its benefit for socio-economic development, and its potential to mitigate climate change. Importantly, bamboo forests are recognised as a large carbon sink in the global cycles of carbon in China.(Chen,Zang ,Zang ,Booth and He (2009)) report that the carbon stocks in bamboo forests increased from 318.55

to 631.58 Tg C between the 1950s and the 1990s. Another example by Zhou *et al.* (2010) indicates that carbon storage in the bamboo forest system in China may have reached 1138.8 Tg C since 2000.

2.7.7 Case Studies of the Growth Patterns of Bamboo Plants

Muthukumar and Udaiyan (2005) conducted a nursery experiment to assess the effect of bio-inoculants (*Glomus aggregatum, Bacillus polymixa* and *Azospirillum brasilense*) on seedling growth promotion of bamboo plants (*Dendrocalamus strictus*) in two soil types (alfisol and vertisol) with and without fertiliser application. Bamboo seedlings were grown in the presence and absence of bio-inoculants, individually and in combinations for 180 days in field soil under tropical nursery conditions. Rhizome sprouts and root length, dry masses, nutrient concentrations and carbuscular mycorrhizal (CM) colonised root lengths were determined at harvest. The author found that fertiliser application enhanced the efficiencies of N, P and K uptake, whereas this reduced their usage efficiencies. Though soil type did not affect the microbial inoculation response, fertiliser application significantly affected plant response to microbial inoculation.

The phenology and culm growth of *Bambusa cacharensis* were studied by Nath *et al.* (2004). The study was conducted in a village called Dargakona in the district of Cachar in South Assam, North East India. The climate is warm and humid with an annual rainfall of 2 660 mm. The village was chosen because many of the household gardens preferred this type of bamboo due to its growth structure and multiple uses (Nath *et al*, 2004). The study was conducted over 12 months starting from July 2003 ending June 2004. The observations depicted in Figure 2-4 below were made on the phenology and culm growth of *Bambusa cacharensis*.

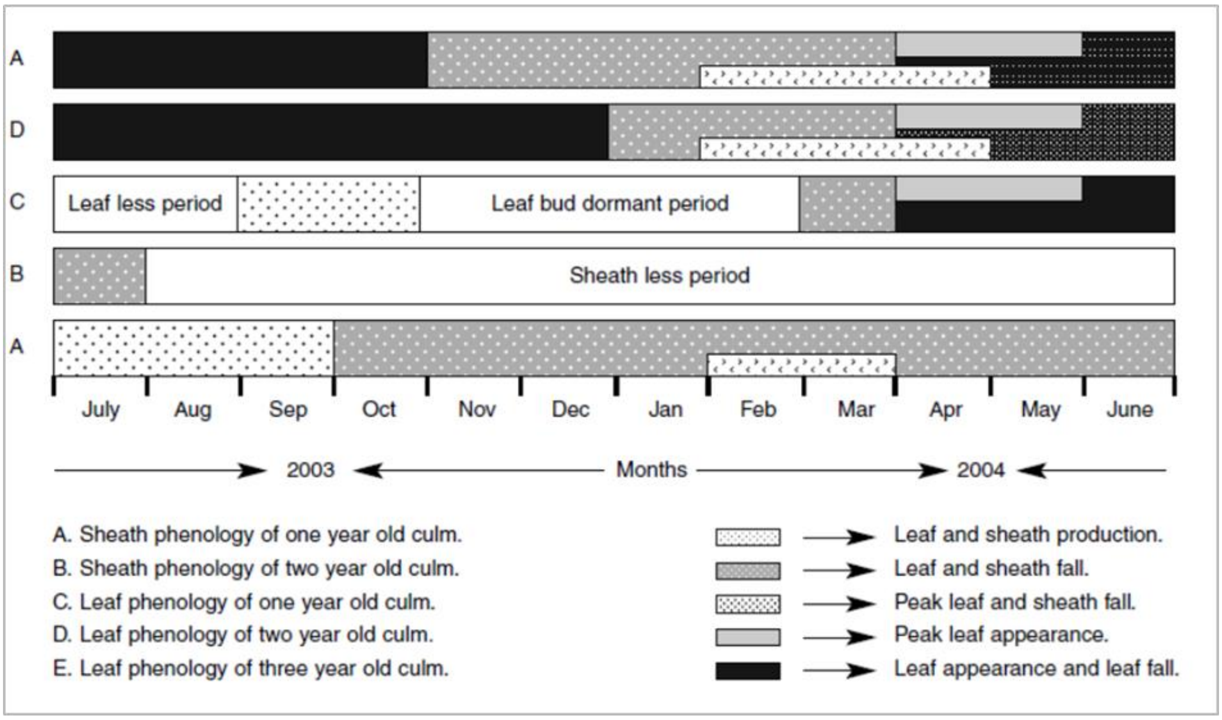

Figure 2-4: Graphical representation of sheath and leaf phenology of one, two and three year's old culm of Bambusa cacharensis (Nath *et al*. 2004)

As indicated in Figure 2-4 above, it was observed that the new culms emerged from June to August (rainy season) and peaking in July. The young culms were light green during this period. The colour of the sheaths changed to light brown and brown at maturity. The sheaths fell in October, i.e. after three months, indicating semi-deciduous nature of culm shot. The culm growth is depicted in Figures 2-5a and 2-5b, and the graphs were plotted according to the formulae seen below:

$$\text{Growth rate} = \frac{Y_2 - Y_1}{T_2 - \mathrm{T}_1}$$

where Y_2 and Y_1 are the height of culm at time T_2 and time T_1, respectively.

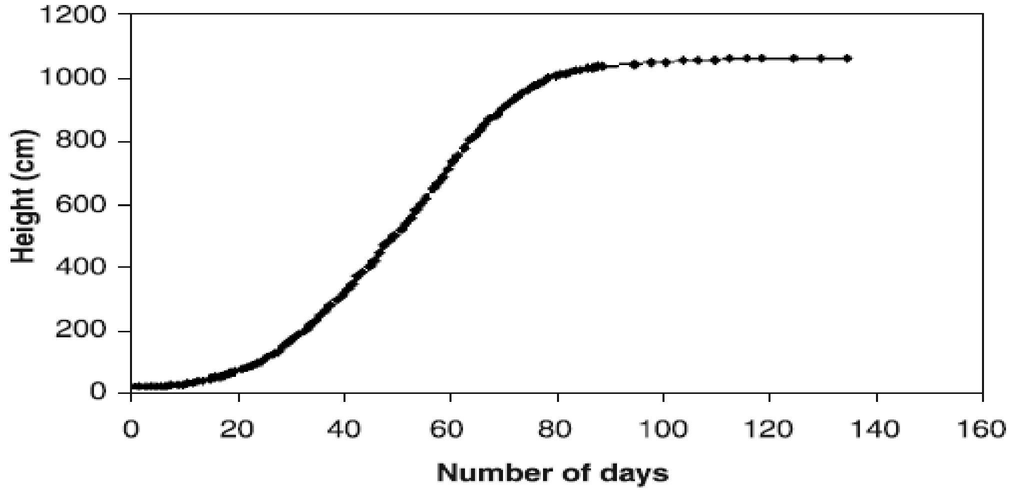

Figure 2-5a: Growth curves for *Bambusa cacharensis* (Nath *et al*., 2004)

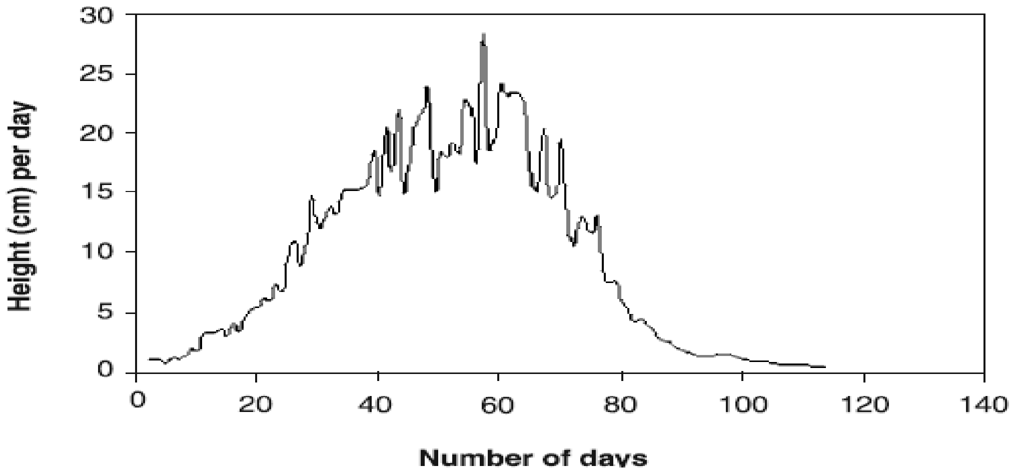

Figure 2-5b: Growth curves for *Bambusa cacharensis* (Nath *et al*., 2004)

The growth curve for the *Bambusa cacharensis* has a smooth S shape curve as illustrated in Figure 2-5a. It can be seen that during the first 15 days, growth is very slow, with only 1.0 cm to 3.0 cm in height per day (Figure 2-5b). However, over the next 40 days, the growth rate increases very fast from 3.0 cm to 28 cm per day. Nearly 66% of the total growth height is attained during 40 days. The growth strategy exhibited by *Bambusa cacharensis* with rapid extension growth and periodic growth, leaf exchange type F leafing pattern along with its multiple uses makes this species a preferred village Bamboo of Barak Valley in North East India.

2.8: Commercial Applications of Bamboo Plants

Bamboo plants' high growth rate and easy processing have resulted in them being a promising renewable energy source that could potentially substitute for slow-growing hardwood. Bamboo has good mechanical properties, low maintenance costs, and is abundantly available in developing countries (Koren, 2016). Its rapid growth and extensive root network make bamboo a good carbon fixator, erosion controller and water table preserver. The bamboo plant is an eminent means to start up reforestation and often has a positive effect on groundwater level and soil improvement through the nutrients in the plant debris. Many species of bamboo have strong, light and flexible woody stem that lend themselves to many applications in construction, agricultural, fishing, musical instrument manufacturing and civil engineering activities. The major applications for the bamboo plant are briefly outlined below.

2.8.1 Construction Activities

In many Asian and African countries bamboo plants are used as poles and scaffolding materials in construction projects. In both traditional buildings and innovative architectural projects, bamboo poles have demonstrated their suitability due to low weight, high strength and durability. In Uganda, in areas surrounding Mgahinga Gorilla National Park, the local people exploits the forest's wild bamboo plants for the construction of huts (Bitariho and Mosango, 2005). In Tanzania, Kenya and Madagascar, certain species of bamboo plants are also widely used as poles, door and window frames, bridges, reinforcing and scaffolding materials in construction projects, as well as pipes in the transportation of water.

2.8.2 Paper, Textiles and Boards

Bamboo plant fibres are relatively long (1.5-3.2 mm) and thus ideal for paper production (El Bassam, 1998). Paper production from bamboo plants in China dates back 2000 years. In India, about 2.2 million tonnes of bamboo plants are processed into pulp per year, making up about two-thirds of total pulp production (Adamson *et al.,* 1978 and INBAR, 1991). At least eight North American suppliers are importing and marketing tongue-and-groove flooring materials made from laminated bamboo, which is said to be hard, durable and dimensionally stable as oak or other hardwood flooring. Bamboo culms are sliced into strips, which are then boiled to remove starch, dried, and laminated into solid boards using urea-formaldehyde adhesives. The boards may be treated with preservatives such as boric acid, before or after laminating, or both, and a darker amber colour may be produced by pressure steaming the bamboo in order to carbonise it.

2.8.3 Food for Animals

Bamboo sprouts provide nutrition for primates, antelopes, buffaloes and elephants. For example, bamboo sprouts are a preferred food for mountain gorillas and can make up 90% of their diet in some periods (Weber, 1981 and Elgar-Berry, 2004). Bamboo sprouts also provide a favoured food for African golden monkeys, thus representing around 60% of their foraging (Aveling, 1984; Twinomugisha and Chapman, 2008). Bamboo shoots of some species are also a well-known feature of Chinese and other Asian cuisine, generally imported into the USA in canned form.

2.8.4 Bamboo to Fuel conversion

Molini and Irizarry (1983) proposed the use of bamboo as a fuel for power generation in Puerto Rico in preference to sugar cane, since its lower moisture content at harvesting obviates the need for drying. Early work on preparing a diesel-like fuel from bamboo culms is cited by Tewari (1992), with the process appearing to have been the pyrolysis of bamboo “black liquor” pulping but does not seem to have progressed beyond the laboratory scale (Piatti, 1947). According to a 2013 study by the Netherland’s Programme of Sustainable Biomass Institute, information about the conversion of bamboo to energy and energy carriers is much less publicized and much still need to be done to improve this situation. Various conversion methods have been reviewed by the Institute, for example, cooking fuel has been observed to be more complicated due to the high density of bamboo, making it hard to cut or chip. Bamboo charcoal and briquette production has been the most simple technology that has been used in China and promoted in Africa for example in Ethopia, Kenya and Ghana.

2.8.4.1: Thermal conversion of bamboo

A limited number of evaluations of bamboo for large scale combustion have been made Scurlock,Dayton and Hames,2000) and more recently by Daza Montano, Pels ,Fryda and Swart (2012) and Bada,Falcon and Falcon (2015) on *Guandua angustifolia* and *Bambusa balcooa*, respectively in Colombia and South Africa. From the investigation conducted by the three authors above, the high heating values (HHV) of bamboo utilized were found in the range of 17 -19 MJ/Kg on dry basis with the ash composition of less than 3% and the heating values are mostly higher than other grasses like straw (Netherlands Agency, 2013).

The challenge faced with the utilization of bamboo or biomass in general as feedstock for power generation is due to its high content of alkali (K and Na) and Chloride content as it increases the risk of slagging, fouling, corrosion and ash agglomeration in the boiler, along with lower heat content (Daza Montano *et al.*, 2012). Both Daza Montano *et al.* (2012) and Bada *et al.* (2015) concluded that for effective utilization of bamboo as an energy source, the raw bamboo could be torrefied or co-fired with coal in order to minimize some of the negative impact of biomass in a boiler.

2.8.5 Vegetation on mine land and degraded land

In South Africa there is virtually no literature with regard to the use of bamboo as vegetation cover on mine rehabilitation, other than various unpublished trial data based on verbal discussion conducted by Harmony Gold, South Africa, which are still at an early stage with virtually no conclusive data. There was another report proposal that was put forward by Ecoplanet for land restoration using bamboo at a Kowie farm in the Eastern Cape Povince (Ecoplanet report, 2014) but the detail and progress status of the project are not known.

Figure 2-6 below illustrates the application of bamboo for rehabilitation purposes in Indian coal mines**.** The bamboo was seen as a fast-growing plant; it was planted on coal spoil in April 2011, and within eight months (November 2011) the cultivated coal dump was overgrown by bamboo. This investigation supported the fact that bamboo can be successfully planted on mined sites for rehabilitation.

Figure 2-6: Rehabilitation of coal mines using bamboo (Peter Pearce, 2014)

2.9: Characterization, Conversion and Processing of Biomass

There are various levels of use of biomass as a source of energy between developing and developed countries, and the difference is based on how a country has developed. In many developing countries, biomass provides the basic source of energy need mostly as fuel wood, animal wastes or crop residues, while in developed countries, only a fraction of their energy requirement comes from agriculture and agro-industrial wastes (Capareda, 2011). In the United States, for example, biomass conversion amounts to about 3.25% of energy supply (EIA, 2002 and Haq, 2002), whereas in Bhutan, biomass accounts for 87% of the total energy (Victor and Victor, 2002). Biomass resources could play a significant role in meeting the energy demand in the future. However, it is always advisable to carefully analyse diverse cultural, socio-economic and technological factors of the region and locality where the conversion is being piloted or implemented (Capareda, 2011).

The primary advantage of biomass as an energy source is its benefit as a renewable energy feedstock and contributing less to global warming, unlike the fossil fuel, coal and gasoline.

Bioenergy production from agricultural crop biomass or residues is gaining interest due to the escalating cost of fossil fuels and the need to mitigate global warming caused by greenhouse gas (GHG) emissions. About 70% of African countries rely on imported energy (Okudoh, Trois , Workneh and Schmidt, 2014). This situation is aggravated by huge unemployment and low gross domestic product (GDP) in these countries. Moreover, limited electricity and lack of access to energy remain one of the most important factors affecting industrial and economic development.

2.9.1 Fuel Characteristics of Bamboo Plants

The University of Georgia Plant Genetic Resources Conservation Unit conducted a study to determine the fuel characteristics of nine bamboo samples. The main objective of the study was to determine the feasibility of using bamboo plants as potential feedstock material for electricity generation as well as to ascertain whether the fuel properties change as the plant grows under carefully controlled conditions (Scurlock *et al.*, 2000).

The moisture contents of the samples ranged from 8-23% with no correlation between the amount of moisture and the age of the sample. From the proximate analysis test conducted, the author found that the ash content of all of the bamboo samples (different ages) was 1% or less, and there was no correlation between ash content and bamboo age. The volatile matter content and fixed carbon of the bamboo samples ranged from 63-75% and 12-17%, respectively, with no correlation with the bamboo sample age. It was also observed that all the bamboo samples had very similar higher heating values, ranging from 19.09-19.57 gigajoules (GJ) /t on a dry basis. These are comparable but slightly lower than most woody biomass feedstock and higher than most grasses and straws (Nordin, 1994). The ultimate analysis results presented bamboo samples of different ages with similar carbon and hydrogen contents. The variation in the nitrogen content of the bamboo samples was within the range of 0.2-0.5%.

Furthermore, a correlation between the composition of the ash (ash constituents) in each of the bamboo samples was found, according to the maturity of the individual species. The ash content of the 4.5 year old *Phyllostachys nigra* samples utilized by this author was found to be lower than the younger samples. A similar increase in ash silicon content was also observed for the *Phyllostachys bisetii* samples and a more gradual increase for the

Phyllostachys bambusoides samples. The amount of alkaline earth oxides, calcium oxide (CaO) and magnesium oxide (MgO) in the bamboo samples appeared to increase as the bamboo plants matured. The alkali index of these samples (defined as kg alkali oxide per GJ energy content) ranges from 0.1-0.3. The low chlorine content of the bamboo samples noted in this investigation implies that in terms of ash deposition, burning of these bamboo samples with low chlorine content is unlikely to enhance high-temperature corrosion in biomass combustion systems.

Another study on the characteristics of bamboo was conducted by Bada *et al* (2015) on raw bamboo and thermally treated bamboo as a feedstock in co-firing with a South African high ash coal. During this investigation, it was found that the ash content and the fixed carbon of the raw bamboo was 0.49% and 6.01%, respectively, with a calorific value of 18.53 MJ/kg. However, after torrefaction and low carbonisation treatment of the bamboo, the calorific value increased to 24 MJ/kg and 28 MJ/kg respectively. The nitrogen content of the raw bamboo was also found to be 0.22%, while the sulphur content in the raw samples was found to be untraceable (Bada *et al.*, 2015).

2.9.2 Energy Generation from Biomass

The history of biofuels is fairly old, since they were already investigated as an automotive fuel in the latter half of the 19th century. Much later, during the first oil crisis of 1973, biofuels were again brought into the limelight. In the USA, favourable tax treatment was given to ethanol blended with gasoline, called “gasohol”. Ethanol production using biomass processing was initiated in 1975 in Brazil during the first oil crisis, and the programme initiated was called PROALCOOL, which stands for Brazil National Alcohol Plan; this programme led to Brazil being a net exporter of about 90% of the world’s ethanol production (ERIA, 2010). The European countries have also embarked on a Carbon dioxide (CO_2) reduction effort through the introduction of bio-diesel fuel and widespread increase in support for diesel-powered passenger cars. Biomass is considered one of the most promising alternatives to conventional fuels because it is the only renewable source of carbon that can be converted into liquid, solid and gaseous fuels.

Biofuel utilisation in Europe and the USA expanded significantly during the 1990s due to the need to improve car exhaust emission performance, reduce CO_2 emissions, and to introduce a renewable energy source to offset the finite petroleum resource. The introduction of domestically sourced biofuels is an important outlet for excess supplies of maize and sugar. According to Sarfo (2008), the conversion of biomass into energy can be done in two main ways as outlined in Figure 2-7 below.

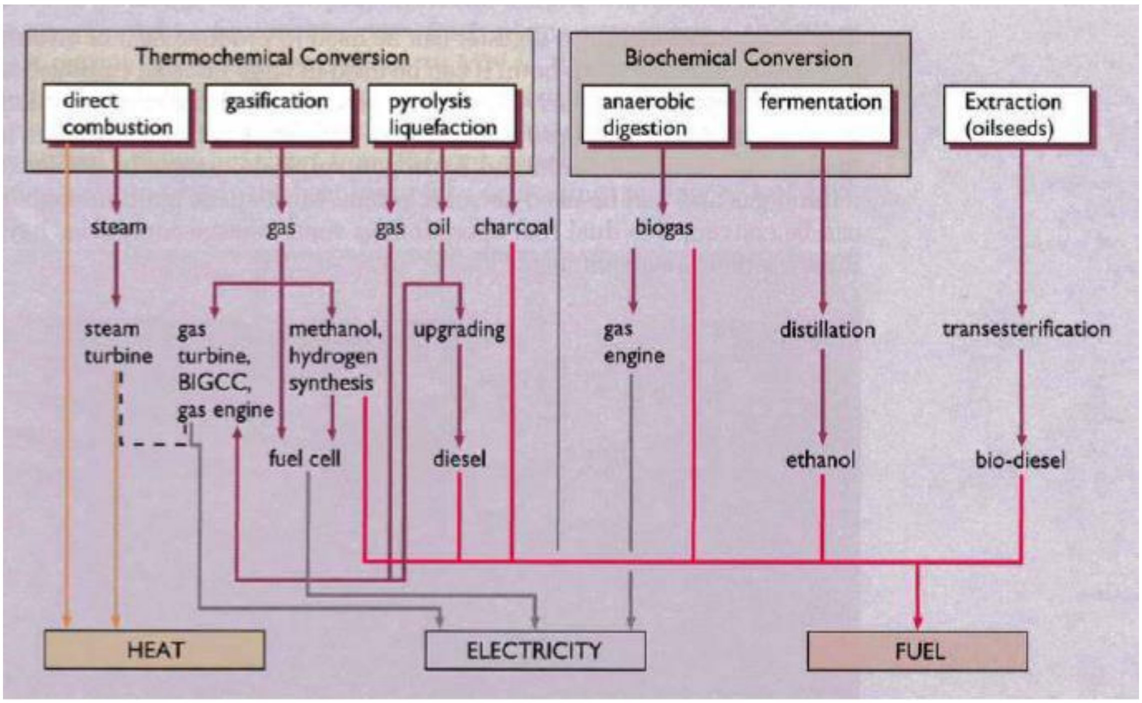

Figure 2-7: Main biomass conversion routes (Boyle, 2004)

2.9.2.1. Thermal Conversion Process

Thermal conversion involves the use of heat, in which the degree of burning varies according to the method being used in the conversion. This process is usually used in the industry to produce steam, which turns turbines to generate energy in the form of electricity (Sarfos, 2008). According to NREL (2006), the process is able to produce liquid fuels and gases, which can replace diesel and petrol that come from an oil refinery. Thermal conversion can be performed in three different ways by direct combustion of solid fuel or co-firing, gasification or pyrolysis.

Direct combustion involves the burning of biomass in the presence of oxygen to produce steam, which causes the turbines to generate electricity. Co-firing is the process of partially replacing a fossil fuel (coal) with biomass in order to control the greenhouse pollution effect (CO_2 in particular) caused by coal in power plants without compromising efficiencies of the power plant (Scurlock *et al.,* 2000). The gasification process converts fossil fuel based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide without combustion, but in controlled oxygen and steam atmosphere at a temperature above 700 °C.

Pyrolysis is the process of burning biomass under limited oxygen in a controlled temperature. According to Blasi *et al*. (1999), at 500°C and under limited oxygen, the thermal destruction of biomass occurs during pyrolysis. The by-product of pyrolysis is usually charcoal (solid char), bio-oil (liquid), and fuel gas product.

2.9.2.2. Biochemical Conversion Process

This process involves the use of biological systems to convert the chemical energy of biomass into biofuels. The conversion processes are less expensive than most of the thermal processes and are ideal for moisture-rich biomass. Variation in oxygen concentration and microbial organisms are employed in the process (Sarfo, 2008). The biomass, once broken into starch and sugar, is turned into alcohol. Starchy crops such as maize, potatoes, barley, wheat and all cellulose materials are sources of sugars that can be converted into alcohol. The most commonly produced alcohol from biofuel is ethanol, which is used in diesel and petrol engines.

2.10: Overview of Bamboo Biomass for Energy Production and other biomass

Bamboo, as energy feedstock, has been studied extensively, mainly in Asia, India and part of Latin America (Truong and Le 2014, Lobovikov et al.2005 and Scurlock 2000). In South Africa, nothing has been done other than a recents pilot study in the Province of KwaZulu-Natal in the district of Illembe; the project entails the cultivation of 500 hectares of land by planting a cloned bamboo, called Beema bamboo. Beema bamboo species is the same as *Bambusa balcooa* that is mainly found in South Africa. In this section, literature from around the world will be reviewed in assessing the bamboo biomass energy conversion potential and other biomass other than bamboo. Truong *et al*. (2015) assessed the suitability of bamboo biomass as a source of energy, and in the assessment, a comparison was made between traditional fossil fuels and bamboo and the results are tabulated in Table 2-2 below.

Table 2-2: Summarised characteristics of fossil fuel and bamboo biomass (Truong *et al.*, 2015)

Criteria	Fossil fuel		Bamboo biomass	
Availability	Positive	Extracted directly from existing reserve and use	Negative	Have to plant and harvest after a period of 3-4 years
Energy produced (per same mass)	positive	Much larger	Negative	Much smaller
Logistic(transportation, storage)	Positive	Easy to transport and store	Negative	More difficult(need larger space for transportation and storage)
Quantity	Positive	Unified	Negative	Vary
Sustainability	Negative	Non-renewable source	Positive	Renewable source
CO_2 emission	Negative	Increase the concentration of CO_2 in the atmosphere	Positive	Not increase the concentration of CO2 in the atmosphere

The assessment in Table 2-2 above was made based on a comparison between different fossil fuels and renewable energy technologies, and it was concluded that bamboo biomass has both advantages and drawbacks in comparison to other sources. However, the biggest advantage that bamboo biomass has over fossil fuels, such as oil and coal is its capability to reduce GHG emission and sustainability; it is also much cheaper to operate than wind, hydro and photovoltaic technologies.

In comparison to most other energy crops like straws, maize, beans, etc. bamboo biomass has better calorific value "heat content". It can grow on degraded land, so it requires less care and less competition with other food crops. The biggest risk with large-scale farming of bamboo is the conversion of natural forest into bamboo monoculture, which may lead to loss in biodiversity (Poppens *et al.*, 2013). Poor climatic conditions could also affect bamboo growth and delay harvesting, thus affecting the investment return of bamboo plantations (Truong *et al.*,2014).

2.10.1 Case study 1: Economic Analysis of Bamboo Plantation in Three Major Ravine Systems of India

India has major landforms cutting across its major rivers and this degrading landform called ravine covers an expanse of approximately 4 million hectares. India has done extensive engineering reclamation of the ravines, and such measures involved extensive capital investment with sustained community development, but these measures are found not sustainable in the long term. A decision was taken by Indian authorities to retire the ravine lands by planting permanent vegetation along the slopes of these ravines (Tejwani ,Gupta and Mathur, 1975). The most suitable plant that was proposed by India was bamboo, as it is the second-largest producer of this plant after China. Bamboo was also proposed because it is well suited for polycyclic harvesting and it can be grown on steep hillsides and along the river banks (Pande, Kurothe, Rao,Kumar,Paraniyal,Singh and Kumar, 2012).

The data utilized in the planting of bamboo in these three ravine systems was generated by the Central Soil and Water Conservation Research at three regional research centres at Vasad (Mahine Ravine), Kota (Chambal Ravine) and Agra (Yamuna Ravine). The costs and benefits have been estimated at between 2010 to 2011 local prices in the three regions, and the present analysis was conducted for a period of 20 years. For financial analysis of the plantation, a discount rate of 8% was used and 2% discount rate for social analysis (Pande *et al.*, 2012). The climate and soil conditions of the three ravines are different, the Yamuna Ravine is found to be semi-arid with an annual rainfall of 755 mm. The Chambal Ravine is characterized by dry sub-humid micro-thermal climate with an average rainfall of 789 mm, while the Mahi Ravine climate is semi-arid with an average annual rainfall of 850 mm. The soil type of the Chambal Ravine, which is deep V-shaped (Dhruva Narayana, 1993), is clay to clay loam and light textured. In the Yamuna and Mahi broad-based U-shaped ravine, the soil is coarse sandy loam in texture.

The economic analysis of these bamboo plantations was carried out using benefit-cost ratio; net present value and internal rate of return. The results of the analysis are highlighted in Table 2-3 below.

Table 2-3: Economic analysis of ravine systems in India (Pande *et al*. 2012)

Description	Mahi Ravine	Chambal Ravine	Yamuna Ravine
Spacing (mxm)	5 X 5	5 X 5	5 X 5
No. of plants/ha	400	400	400
Mortality replacement%	20	20	30
Manure required (kg/plant/year)	10	10	10
Fertilisers required (kg/plant/year)	0.02	0.02	0.02
Cost of fertilisers(R/kg)	1.65	1.65	1.65
Irrigation cost/No. (R)	87	139	17.4
No. of irrigations/year	15	8	21
Seedling price (R/Seeding)	0.86	0.86	1.13
Labour wages (R/Man-day)	21	21	26
No. of harvestable plants per ha (%)			
(i) Initial four years	30	30	30
(ii) Fifth years onwards	40	40	40
Sale price per bamboo pole (Rands)	**6.08**	**6.08**	**7**

Note: The currency was converted from Indian Rupee to Rands using 2012 Rand to Rupee exchange rate

Table 2-4: Unit costs in ZAR Rand for raising 1ha bamboo plantation in the Mahi Ravine system in India, 2012(Pande *et al*., 2012)

Items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Total
Materials								
Planting material, including 10% mortality replacement in year 2 and year 3	800	80	80					960
Manure and fertilisers (DAP) (50g/plant)	190							190
Plant protection (LS)	600							600
Irrigation, 15 No. (R87 per irrigation)	1 305	1 305	1 305	1 305				5 220
Subtotals	**2 895**	**1 385**	**1 385**	**1 305**	**0**	**0**	**0**	**6 970**
Labour (Man-day)								
Land preparation (LS)	6 650							6 650
Digging of trenches, refilling @ R8 per trench (400 No.)	3 200							3200
Planting and staking (400 No.)	6 000	600	600					7 200
Soil working and others		2 000	2 000	2 000	2 000	2 000	2 000	12 000
Watch&ward (LS)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	21 000
Harvesting – 7th year onwards							6 000	6 000
Subtotals	**18 850**	**5 600**	**5 600**	**5 000**	**5 000**	**5 000**	**11 000**	**52 850**
Contingency (5%)	943	280	280	250	250	250	550	2 643
Grand total	**22 688**	**7 265**	**7 265**	**6 555**	**5 250**	**5 250**	**11 550**	**62 463**

LS: Lump sum; and DAP: Diammonium phosphate

Table 2-5: Unit costs in ZA Rand for raising 1ha bamboo plantation in the Chambani Ravine system in India, 2012

Items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Total
Material								
Planting material, including 10% mortality replacement in year 2 and year 3	2 000	200	200					2 400
Manure and fertilizers (DAP) (50g/plant)	190							190
Plant protection (LS)	600							600
Irrigation, 8 No. (R139 per irrigation)	1 112	1 112	112	112				4 448
Subtotals	**3 902**	**1 312**	**312**	**112**				**6 848**
Labour (Man-day)								
Land preparation (LS)	6 000							6 000
Digging of trenches, refilling @ R8 per trench (400 No.)	3 200							3 200
Planting and staking (400 No.)	2 800	280	280					3 360
Soil working and others (2)		3 600	3 600	3 600	3 600	3 600	3 600	21 600
Watch and ward (LS)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	21 000
Harvesting – 7th year onwards							6 000	6 000
Subtotals	**15 000**	**6 880**	**6 880**	**6 600**	**6 600**	**6 600**	**12 600**	**55 760**
Contingency (5%)	750	344	344	330	330	330	630	2 788
Grand total	**19 652**	**8 536**	**7 536**	**7 042**	**6 930**	**6 930**	**13 230**	**65 396**

LS: Lump sum; and DAP: Diammonium phosphate

Table 2-6: Unit costs in ZAR Rand for raising 1ha bamboo plantation in the Yamuna Ravine system in India, 2012

Items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Total
Material								
Planting material, including 30% mortality replacement in year 2 and year 3	2 600	780	780					4 160
Manure and fertilisers (DAP)(50g/plant)	190							190
Plant protection (LS)	600							600
Irrigation, 21 No. (R17.40 per irrigation)	365.4	365.4	365.4	365.4				1 461.6
Subtotals	**5 383.4**	**1 145.4**	**1 145.4**	**365.4**	**0**	**0**	**0**	**8 039.6**
Labour (Man-day)								
Land preparation (LS)	6 000							6 000
Digging of trench, refilling @ R5.20 per trench (400 No.)	2 087							2 087
Planting and staking (400 No.)	14 000	4 200	4 200					22 400
Soil working and others (2)		5 000	5 000	5 000	5 000	5 000	5 000	30 000
Watch&ward (LS)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	21 000
Harvesting – 7th year onwards							6 000	6 000
Subtotals	**25 087**	**12 200**	**12 200**	**8 000**	**8 000**	**8 000**	**14 000**	**87 487**
Contingency (5%)	1 254	610	610	400	400	400	700	4 374
Grand total	**31 724.4**	**13 955.4**	**13 955.4**	**8 765.4**	**8 400**	**8 400**	**14 700**	**99 900.6**

LS: Lump sum; and DAP: Diammonium phosphate

Table 2-7: Economic analysis of bamboo cultivation in selected ravines of India: January to June 2012

S. No.	Parameters	Mahi ravines	Chambal ravines	Yamuna ravines
1	NPV (R/ha/year)	1 045	980	1 222
2	Benefit-cost ratio	1.85	1.76	1.89
3	IRR (%)	18.4	18.1	19.3
4	Payback period (years)	10	10	9

NPV: Net Present Value; R: Rand; ha: hectare and IRR: Internal Rate of Return

Table 2-7 above shows that the bamboo plantation project achieved positive net present value at all three ravines with Yamuna and Mahi giving good return at R1222/ha/year and R1045/ha/yr, respectively. The cost benefit ratio of greater than 1% indicates that the labor is profitable and in this instance, all the three ravines achieve cost benefit ratio of above 1% with Mahi and Yamuna performing well at 1.85 and 1.89 %, respectively. Altogether the project will provide a return on investment and become profitable at year 9 for Yamuna and Year 10 for Chambal and Mahi Ravine system.

Conclusion from the Case Study

Based on the foregoing data from these tables above, it was concluded that bamboo plantation for productive and protective utilisation of degraded lands is a profitable option for local stakeholders and also an economically viable policy option for funding agencies and the government. The analysis concluded that the three systems (Figures 2-4 to 2-6) results in positive cash flow in the seventh year onwards of about R5 313/ha to R8 348/ha using 2012 Rupee to Rand exchange (Pande *et al*., 2012). The net present value of the three systems is positive and achieved an internal rate of return of 18.1 to 19.3.

2.11 Economic Evaluation Case Studies of Other Woody Biomass

2.11.1 Case Study 1: Techno-Economic Evaluation of Biomass Conversion in North-Eastern Europe

Grundmann, Luckhaus, Heirmann, Hellebrand and Jacobs (2004) conducted a study at Bornim Institute of Agricultural Engineering in Germany to look at the techno-economic feasibility of utilising biomass in electricity generation via the gasification and fermentation route along the north to south gradient in a region located along the border between Poland and Germany. Energy crops such as woods, straw, forage, forest wood and vegetation waste materials were used as the potential feedstock materials. The following observations were made using Biomix modelling and GIS tools as seen in Figure 2-8 below.

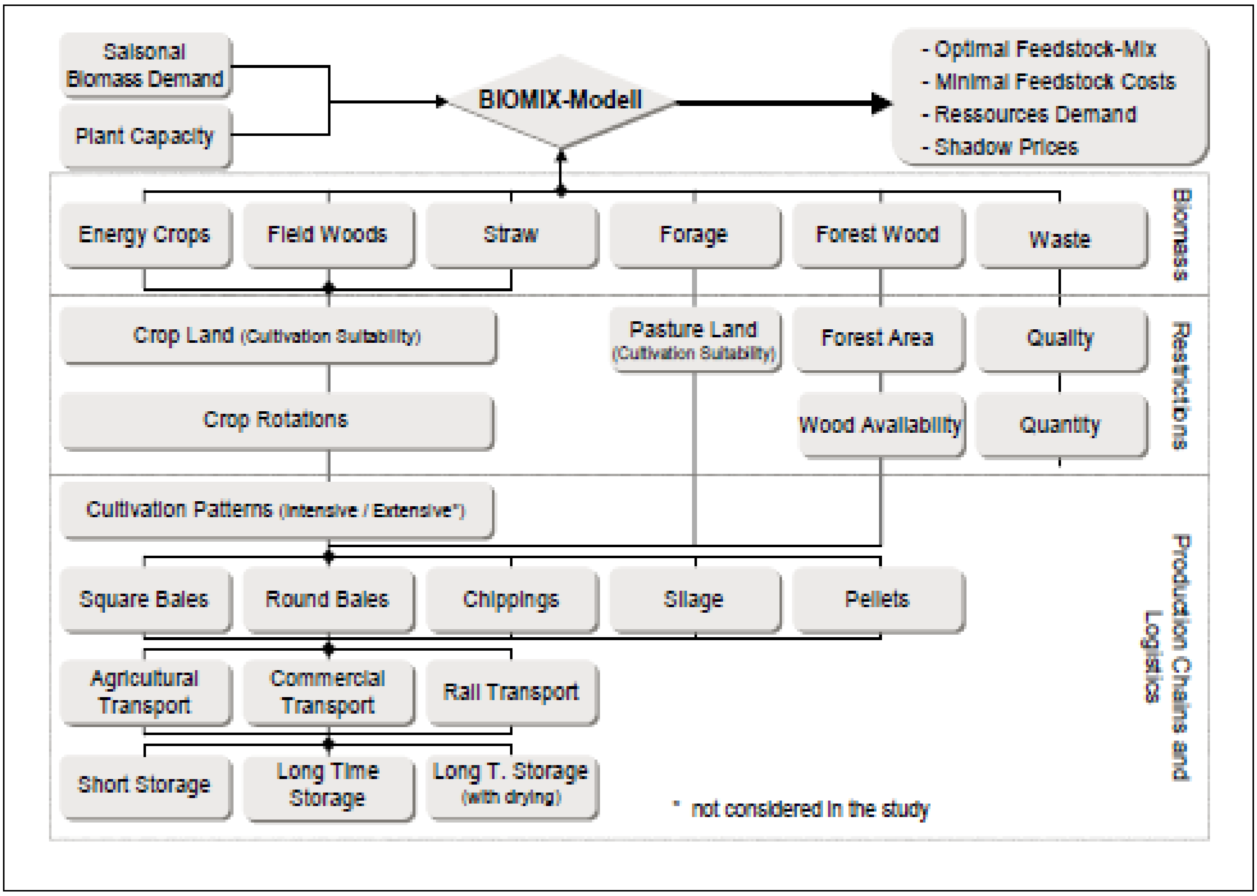

Figure 2-8: BIOMIX model structure (Grundmann *et al*., 2004)

The feedstock cost analysis of the case study above indicated that machinery and cultivation inputs (seeds, fertilisers and plant protection agents) constituted a large proportion of the overall plantation costs. The costs were an average of R440 per tonne of energy crops and forest wood matter content, and R220 per tonne of dry matter content respectively in 2004. It was further noted that the production costs depend on the cultivation of specific species of feedstock material and the chosen supply chain. It was more cost-effective to produce square bales and chippings chains for low moisture biomass, at R880 and R660 per tonne of dry matter content, respectively. These costs are indicated in Figures 2-9 and 2-10 below.

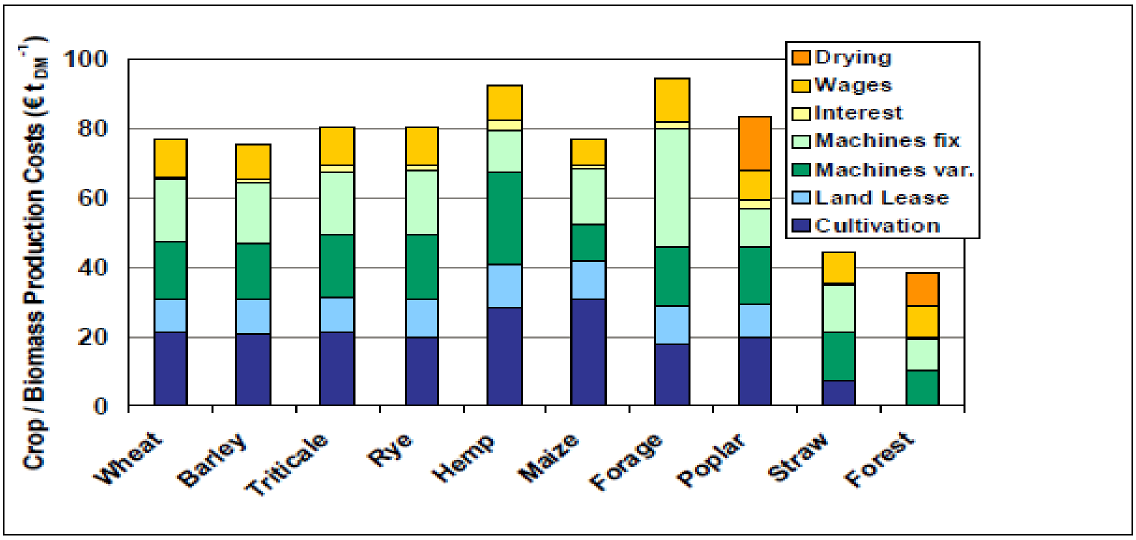

Figure 2-9: Energy crop production costs (Grundmann *et al*., 2004)

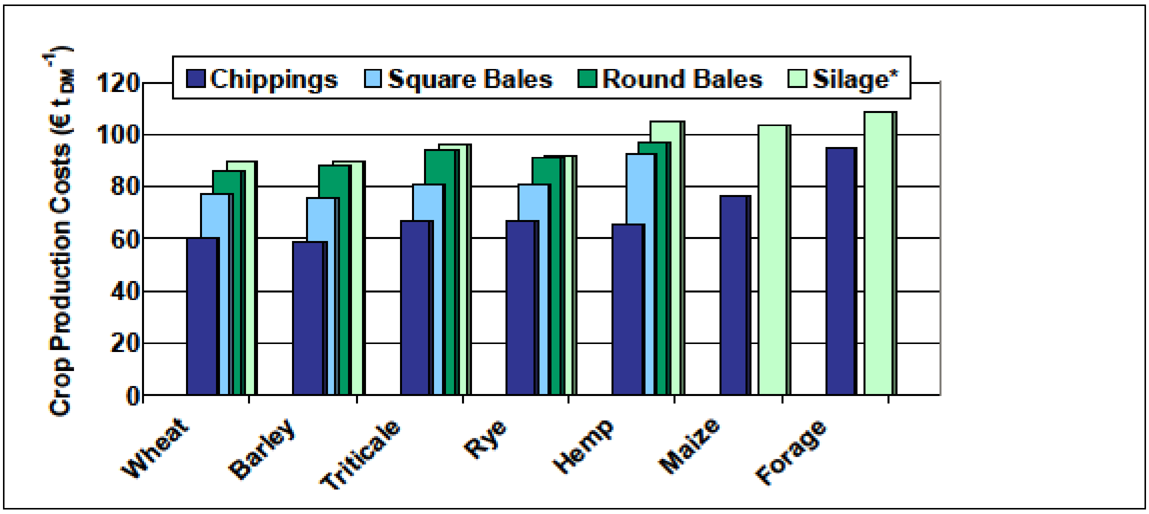

Figure 2-10: Cost impact of supply chains (Grundmann *et al*., 2004)

Grundmann *et al.* (2004) noted that the cultivation of field woods can result in positive ecological effects due to, among other matters, relatively low gas emissions and high heavy metal accumulations in trees. It was noted that the cultivation of field woods such as *Miscanthus* has rarely been practiced by farmers due to legal and economic obstacles in the country. Table 2-8 below shows the environmental implications of grain and maize crops, field woods and residues on the environment. The Table (Table 2-8) indicates that field woods such as *Miscanthus* plant species have a positive impact on land and soil sustainability.

Table 2-8: Environmental implications of energy crops (Grundmann *et al.*, 2004)

	Grain	Maize	Field Woods	Landscape Residues
Soil erosion	Positive	Negative	Positive	Very positive
Soil compaction	No	Negative	Positive	Posiive
Soil fertility conservation	Positive	Negative	Very positive	Very positive
Plant protection agent applications	Negative	No	Positive	Very positive
Fertlizer application intensity	No	No	Very positive	Very positive
Water resources demand	No	Positive	Negative	No
Nutrient leaching	No	Negative	Very positive	Very positive
Land resources demand	Positive	Positive	Positive	Negative
Nitrogen input intensity	No	No	Very positive	Very positive
Gas emissions	No	No	Positive	Posiive
Biodiversity	Negative	Negative	Positive	Very positive
Human health risk during storage	No	Negative	No	Negative

The author, also evaluated two energy generation routes using biomass, namely fermentation through anaerobic digestion plant and thermo-chemical conversion via gasification and Fischer-Tropsch synthesis technology. It was established that under regulated prices of electricity of R1 749 on plant capacity of 500 kW/h and electricity price of R1 419 the dry matter co-digestion with slurry is cost-effective in contrast to the situation where electricity prices are not regulated and there are no best practices on biomass with high dry matter content.

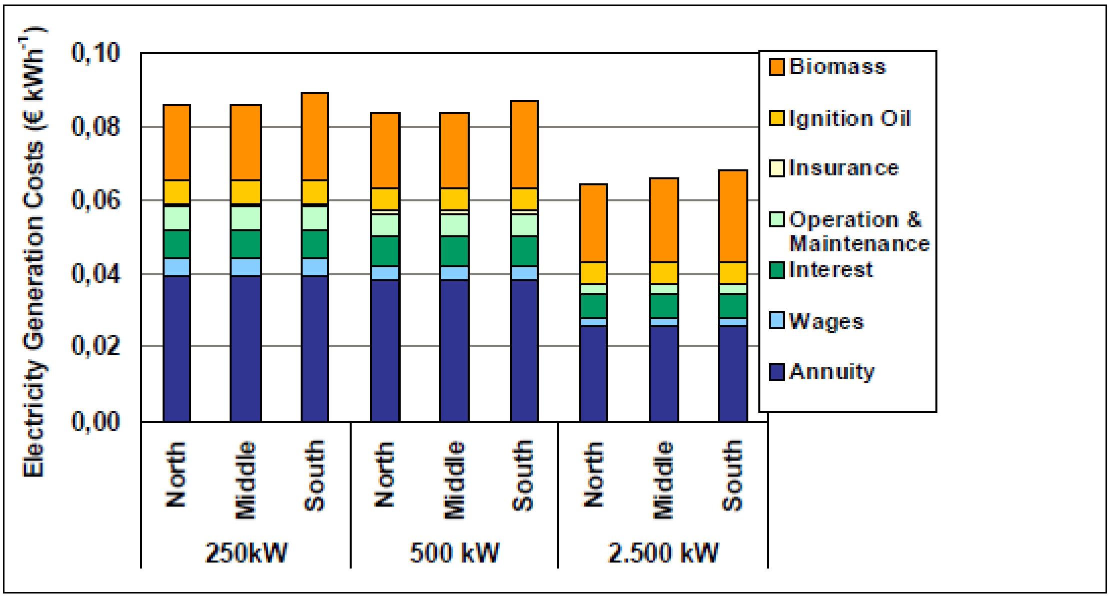

Figure 2-11: Electricity production costs in anaerobic co-digestion plants (Grundmann *et al*., 2004)

The Gasification of biomass was modelled by the same author using a 50 Megawatt (MW) capacity gasifiers. These plants are characterised by large-scale, centralised biomass procurement and logistics processes. Grundmann *et al.* (2004) established that the gasification of biomass is technically feasible, but not economical and ecologically desirable due to high toxic content and lower thermal efficiency as a result of loss in calorific value during partial conversion processes. It was further noted that the economic scale of larger biomass gasification is highly vulnerable to changing prices and feedstock availability, since feedstock costs represent 30-50% of the final product costs, see Figure 2-12 below.

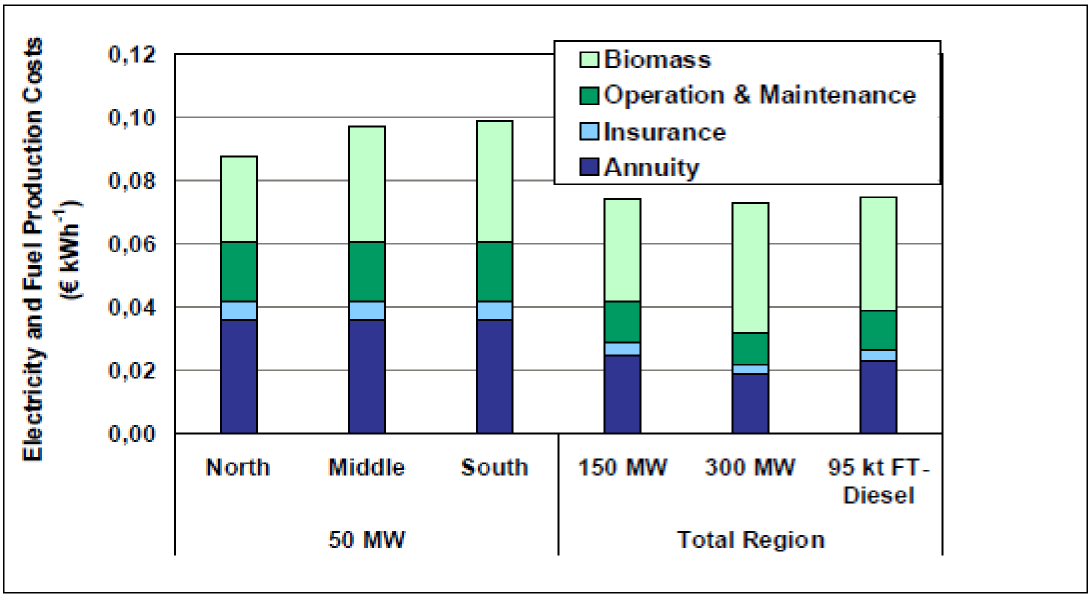

Figure 2-12: Electricity and fuel costs of biomass gasification and F-T synthesis plants (Grundmann *et al.*, 2004)

Conclusion from Case Study 1

Grundmann *et al.* (2004) established that for large-scale biogas gasification projects involving Fischer-Tropsch synthesis, macroeconomic uncertainties, including government policies on energy prices are major economic risks. Therefore, short-term preferences are based on the economic advantages of conversion routes suitable for a wide range of low biomass inputs. Profitability is only achieved in an environment where the price of digesters is regulated, since digester plants make use of energy crops with high moisture content. Gasification plants are basically fed with straw and wood plants whose yield and cost variations indicate potential for improvements, including selecting crops and crop rotation according to the suitability of the land and optimising supply chain management. Further advances on biomass conversion into energy are expected in the middle to long term as a result of ongoing research and development including identification of new crop varieties as well as improved technologies (Grundmann *et al.*, 2004).

2.11.2 Case Study 2: Techno-Economic Evaluation of Reed in Biomass Production in Wuliangsuhai Lake (Inner Mongolia)

China is the world's most populous country with about 1.36 billion people in 2013. The industrialization and urbanization of China have resulted in a high overall demand for energy, and the quest to secure future sources of supply of energy has led the country to investigate alternative sources of energy. Rapidly increasing energy consumption volumes, particularly for coal and liquid fuels, has resulted in China becoming an influential player in global energy markets. In 2011, China became the second-largest global energy consumer after the USA with approximately 70% of its electricity being produced from coal that is cheaply and widely available in the country (Kobbing, Patuzzi, Baratier, Beckmann, Thevs and Zerbe ,2014).

China is planning to diversify its energy mix and increase its share of renewable energy sources from 8% in 2013 to approximately 15% in 2020 (Moch, 2013). In China, wind, photovoltaic, and hydropower have been used for electricity generation, while biomass – representing 8.9% of the total energy in China – has been mainly used in rural areas for heating and cooking (UNDP, 2007 and Moch, 2013).

Table 2-9: China's energy balance in millions of tonnes of oil equivalent [Mto] on a net calorific value basis for 2011 (EIA statistics , 2013)

	Production	Imports	Exports
Coal and Peat	1823.4	98.8	18.2
Crude and Oil products	203	308.8	33.4
Natural gas	85.9	24.5	2.9
Nuclear	22.5	0	0
Geothermal, Solar,Hydro,etc	101.2	0	0
Biofuel and waste	218.4	0	0
Electricity (MW)	0	0.6	1.9
Total	**2454.4**	**432.7**	**56.4**

The co-firing of biomass in conventional coal plants only took place at pilot scale, as there were no financial subsidies in China to undertake any larger-scale tests (Wang and Shen,1987). It is estimated from the literature that the potential reed (*Phragmites*) biomass in China is approximately 4.2 million tonnes, and 95% of this is used in paper production. Closure of paper production facilities, however, has now made the biomass resource available for energy generation (Kobbing *et al.,* 2014). In this case study, the evaluation of the economic potential of the common reed in energy production was done by modelling four different scenarios that are as follows:

- decentralised application in the household;
- Centralised reed supplied combined heat and power gasification;
- a direct combustion plant; and
- a co-firing in existing plants.

The feedstock (reed) energy characteristics are the moisture and ash content, the lower heating value, and the elemental composition of the biomass as conducted by the author is depicted in Table 2-10 below.

Table 2-10: Chemical and physical characterisation of reed (*Phragmites.australis*) stem tissues (Kobbing *et al*., 2014)

IDs	Unit	2	3	4	5	6(S)	7	7(S)	8	9	10	11	12	13
Moisture	$\%Wt_{w}$	16	32.2	62.4	47	12.2	31	12.8	12.7	20.9	27.5	24	51.7	20
Ash	$\%Wt_{dry}$	3.8	4.2	3.3	4.4	4.3	4.5	2.7	7.1	7	7.8	3.3	6.8	5.2
LHV	MJ/Kg_{d}	17	16.9	17.5	17	17.2	17	17.8	16.8	17	16.7	17.4	16.4	17
C	$\%Wt_{daf}$	49	49.3	48.8	48	49.1	49	49	49	48.7	48.7	49.2	49.2	49
H	$\%Wt_{daf}$	6.4	6.5	6.4	6.4	6.5	6.4	6.4	6.5	6.2	6.4	6.6	6.7	6.4
N	$\%Wt_{daf}$	0.3	0.4	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.4	0.2	0.4	0.5
O	$\%Wt_{daf}$	43	42.5	43.4	45	42.9	43	44	43.4	43.9	43.3	43.4	42.4	43
S	$\%Wt_{daf}$	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
Cl	$\%Wt_{daf}$	0.9	1.2	0.9	0.7	0.8	0.6	0.2	0.7	0.8	1.1	0.5	1.1	1.1
P	**mg/kg_{d}**	**119**	**287**	**61**	**103**	**116**	**176**	**181**	**181**	**86**	**126**	**71**	**240**	**175**

(S)=Storage ,daf:dry ash free

According to Kobbing *et al.* (2014), moisture content, among other parameters, remains the most important parameter in thermo-chemical conversion of biomass. Pre-treatment drying needs to be done before processing because the high moisture content biomass becomes an added cost. High chlorine and sulphur content can cause problems of emission and corrosion, and thus it needs to be considered during the process design and impact stage. Another parameter that needs to be considered is high ash content, particularly if the melting temperature of the ash is low, which can result in the formation of slag (Kobbing *et al.,* 2014). The results show that reeds are a suitable feedstock in medium temperature processes, i.e. lower than 800 and 900^{o}C. Moreover, reeds are able to accumulate pollutants due to its phytodepuration potential (Weis and Weis, 2004).

The energy market in the studied area "Wuliangsuhai", was evaluated according to the data collected in the study (Kobbing *et al.,* 2014), by means of interviews from the participants in the Wuliangsuhai energy sector. The coal price in 2011/12 was roughly 480 Chinese Yuan/t, equivalent to R624 at 2011 exchange rate as per appendix F. It is stated that the situation is different in rural areas, as the coal is sold in village coal shops to households at a market price of 700-780 Chinese Yuan/t (R910-R1014). Between 2 and 3 tonnes of coal are required to provide heat and power to a small family of between three and four people per annum (Kobbing *et al.,* 2014).

It was estimated that in the Wuliangsuhai Lake area, an annual reed biomass of 100 000 tonnes are harvested in winter from a total area of 188 km^2, which corresponds to half of the lake area (5.3 tons/ha/yr). The harvested reed is then collected in winter by local farmers, stored, pressed into bales and transported for about 700 km to paper mills in Ningxia (Kobbing *et al*., 2013). This transport cost lowers the benefits of local harvesters, and in the long run, utilisation possibilities with higher benefits will have to be found. Harvested reed raw material originating in the Wuliangsuhai Lake area was priced at 370CNY /tonne in 2011 according to Kobbing *et al.*, 2014 and using 2011/12 exchange rate as per appendix F this is equivalent to R481/tonne. The average ground yield and calorimetric energy content of reed is 242 400 MJ/ha. Kobbing *et al.* (2014) stated that considering the present harvested amount of reed biomass of 100, 000 tonnes/annum (corresponding to 5.3t/ha on the total reed area) and material loss of 12%, the present utilisation of reed is equivalent to a total energy input of about 1 327 tonne/J.

Table 2-11: Potential thermal power and heating capacity (Kobbing *et al*., 2014)

	Present	**Potential**	
Harvested amount(t/ha)	**5.3**	**14.1**	
Scenario 1	276	925	GWh_{th}
(biomass furnaces)	8.53-9.60	28.55-32.12	thousands of flats
Scenario 2	84	281	GWh_{el}
(CHP gasification)	206	689	GWh_{th}
	6.36-7.15	21.28-23.94	thousands of flats
Scenario 3	90	301	GWh_{el}
(CHP combustion)	231	775	GWh_{el}
	7.14-8.04	23.91-26.90	thousands of flats

The ratio between the average lower heating value of Chinese coal (about 23 MJ/kg for Run of Mine) and the heating value of reed (15 MJ/kg) means that the amount of reeds required to compensate for the heating value of coal is about 53% higher. Table 2-11 above also shows the present and potential heat output from using reed as a feedstock.

The economic assessment of energy output/heating values of reed and coal under different technologies, along with the reed price and coal prices at R481/tonne and R442-R533/tonne, respectively, are calculated in Table 2-12. The Table reveals that the cost of production per MJ/kg of energy in Rand for scenario 2 and scenario 3 is the same and higher than both conventional methods of electricity generation and co-combustion when adjusting 2004 to 2011 Figures (Kobbing *et al.,* 2014).

Table 2- 12: Heating value and prices for reed and coal at Wuliangsuhai wetland (Kobbing *et al*., 2014)

	Present situation		Scenario1	Scenario2	Scenario 3	Scenario4
	Rural coal	Coal plant	Biomass furnaces	CHP gasification plant	CHPplant fed by reed	Co-combustion 20% reed, 80% coal
LHV(MJ/kg)	23	23	15	15	15	21
Average purchasing price per kg (Rands)	0.96	0.49	0.64	0.56	0.56	0.5
Rands per MJ/Kg	0.042	0.02	0.04	0.038	0.038	0.023

In terms of the economic feasibility of biomass as a source of energy, the author maintains that under current market conditions, the use of reed as an energy source looks promising for combustion in reed stoves. Considering an efficiency of 40% for the coal stoves and the average utilisation of 2.5 tonnes per year, the annual heat demand of a rural house can be estimated to be about 6 400 kWh. Scenario 2 from gasification and scenario 3 for direct combustion is deemed not profitable under current market conditions, unless these are coupled with renewable energy subsidies and lower coal prices. A theoretical net present value (NPV) with assumptions, such as interest rate of 3%, annual operation time of 7 500 hr and plant life of 20 years was created to assess the possible profitability and return on investment of two scenarios using 10 MW and 30 MW plant size for both combined heat and power (CHP) gasification and CHP direct combustion using reeds. The following assumptions stated below were made for a gasification plant:

- An initial investment cost of R33 million per MW for 10 MW and R23 million for 30 MW; and
- Operational and maintenance costs of R11 million and R4.3 million per MW for the 10 MW and the 30 MW plant size respectively.

Table 2-13: NPV and payback period for power from gasification and direct combustion (Kobbing *et al*., 2014)

Power plant setting	CHP gasification		CHP direct combustion	
Plant size	10 MW	30 MW	10 MW	30 MW
Annual electricity production (MWh)	75000	225000	75000	225000
Annual amount of reed (Thousand tonnes)	78.56	235.67	73.4	220.21
Annual costs(Millions of Rands)				
Reed	44.02	132	41.13	123.4
Operation and maintenance	70.82	84.86	17.5	52.4
Annual benefits (Million of Rands)				
Selling electricity	73.13	219.4	73.12	219.4
Annual net benefits(Million of Rands)	-41.72	2.47	14.55	43.63
Present value of annual net benefits(Million of Rands)	-620.66	36.74	216.37	649.1
Total investment (Million of Rands)	215.32	452.26	124.18	372.52
NPV(Million of Rands)	-835.96	-415.52	92.19	276.59
Payback period (Years)		183.1	8.5	8.5

The conclusion drawn from case study 2 under the 2011 China energy market conditions, establishes that the reed was a potential energy feedstock and was shown to be profitable at the family level. CHP plants were more sustainable due to government subsidies that the Chinese government was not offering at that time. The Gasification CHP plants were found not to be economically feasible under the 2011 market conditions. The results indicated that reed biomass could be a sustainable alternative source of energy to coal.

2.11.3 Case study 3: A model for the economic evaluation of biomass plantation for coal co-firing and electricity generation in the USA

The study was conducted in 1999 as a national strategy to reduce levels of CO_2, SO_2 and NO_X in stack emissions as well as to respond to state legislative mandates requiring the use of renewables (Nienow,McNamara,Gillespie and Preckel, 1999). The biomass investigated in the study includes woody biomass, e.g. poplar, willow crops and *salix*. The three types of biomass were found suitable compared to other woody and herbaceous biomass due to their moisture content, calorific value, availability, growth rate, tolerant to extreme environmental conditions and widespread nature (DOE, 1996). The willow crops, according to Borjesson (1996) can produce 5.4 tons of biomass per hectare when using optimum fertilisation and irrigation methods.

The conclusion drawn from the investigation was that co-firing of biomass was not cost competitive with coal or natural gas. Biomass fuel costs for selected DOE programs ranged from R5.8 to R10.9 per 1.06 million kilojoules (kJ) using 1996 South African exchange rate ($1 = R4.30), compared to coal cost of R3.8 to R5.8 per 1.06 million kJ (Moore, 1996). The model also indicated that by co-firing woody biomass at the Michigan City power plant, the process could be a financially viable method to reduce the number of pollution permits needed. The lack of adoption has been primarily due to the low cost of traditional fuels over the last decade (Moore, 1996). However, the reductions in greenhouse gas emission agreed to at Kyoto, Japan in 1997 have the potential to substantially influence and increase the cost of electricity production in years to come from coal utilization.

2.11.4 Case study 4: Southern African Developing countries region for growing Biomass for Bioenergy

A study was undertaken by the Cane Resource Network Southern Africa, to evaluate how bioenergy from sugarcane can support sustainable development and improve global competitiveness in the region. Six countries in the SADC region were evaluated using GIS to map areas with suitable parameters in growing sugarcane and expanding the current production areas. In the assessment, it was found that 6 million hectares are suitable for planting sugarcane within the region and therefore, land will not be an issue for sustainable sugarcane bioenergy farming (Watson, 2010).

The use of cassava as a potential resource for bioenergy production and biogas study was conducted at the University of KwaZulu Natal in Pietermaritzburg, South Africa, as a possible alternative (Okudoh,Trois,Workneh and Schmidt,2014). Cassava is a starch-rich staple food for many African countries, but it is not much grown in South Africa, and it is not a staple diet and therefore not a threat to food security. It was concluded that for sustainable cassava biogas production in South Africa, rural production should first be prioritised and regulated by the national government (Okudoh *et al.,* 2014).

A current limitation that can negatively affect the development of bioenergy as a whole is the availability of water. Arable land is about 14% of the total available land mass, and 10% of this land is irrigated, consuming 60% of the national water supply (Okudoh *et al.,* 2014). The conclusion drawn from these investigations is that, land availability is not an issue, but the debate on food security and availability of water are the main challenges. Bamboo offers many benefits in that it can grow on deprived land and not a threat to food security in South Africa and the SADC.

A study was conducted on the modelling of economic returns to labour for *Jatropha* cultivation in Southern Africa and India at different local prices. This study formed part of the contribution to a series of studies in biodiesel research in South Africa. *Jatropha curcas* L, produces an inedible oil seed with good properties for biodiesel, and was considered as one of the plant species that is suitable for producing diesel in South Africa due to its high yield and environmental tolerance (Borman ,Von Maltitz, Tiwari and Scholes,2013).

Another motive for the study was based on a range of socio-economic and environmental conditions in South Africa, which makes the plantation of *Jatropha* desirable. The two parameters that were studied in detail between South Africa and India was based on retail fuel prices for 2013 and minimum wages of the two countries, respectively. The model was structured in three ways using a top-down systematic approach to calculate the different prices based on the activities involved in the series:

- Modelling Factory Gate price;
- Modelling the Farm Gate price; and
- Modelling the maximum farm labour wage.

The conclusion from the *Jatropha* case study is that the model applied provides a robust mechanism for exploring the consequences of a variance in yields, i.e. the correlation between yields and financial viability of the process. The model results depend on several input assumptions stated below and many of which are generic in nature and are as follows:

- *Jatropha*, in this model, was found not to be viable from a labour and oil price perspective in South Africa compared to India and Zambia where cost of labour is very cheap;
- High local fuel prices increase the chances of profitability provided wages are very low; and
- The key cost in *Jatropha* production is labour because it does not require mechanisation and fertilisers for production, and therefore, it can be a good potential crop for biodiesel production in Africa and India.

2.12 Bamboo growing in South Africa

The most common bamboo species being planted in South Africa is the *Bambusa balcooa* and this is not a native plant as it comes from the IndoChina region. This species was introduced into the country by Dutch traders from Northern India in the early 1600s. The *Bambusa balcooa* that was originally planted on Westerford farm (Newlands) in the late 17th century has never spread as an invasive species since it was planted. The same species is now found in the grounds of the Western Province Rugby Union (Biomass Corporation Website, 2016).

This species of bamboo is mainly found in indigenous South African forests and it grows on small farmlands. The quantity of bamboo species growing on farmland is not known since there has not been any inventory undertaken within South Africa. Other species have been planted in demonstration plots established at various ecological zones throughout the country as part of a bamboo promotion strategy. *Bambusa balcooa* is currently being cultivated on coal and uranium mine dumps in the Mbombela and Klerksdorp districts respectively on an experimental basis (Landu and Mashai, 2011).

Very few bamboo species grow naturally on farms in the Eastern Cape Province. In the Drakensberg region in KwaZulu-Natal Province, the indigenous species called *Arundinaria tessellata* is found (UP archived, 2014). This species was once used to make whip-sticks in the days of ox-drawn wagons by the Zulu nation. According to Mary-Ann Fairall of Bamboo for Africa Programme, bamboo plants are currently being grown at the Renewable Energy Solutions (RES) farm in Westonaria, Gauteng Province. Moreover, bamboo is also planted at the Blue Disa farm in Ennerdale, Western Cape Province Province, Green Bushes farm in the Eastern Cape Province and also at schools in Ulundi in KwaZulu-Natal Province.

Bamboo trial plantation is mainly restricted to the coastal area of the country and few attempts were made within the inland but none of the data on inland plantation are available in the literature.

Bamboo plantation in South Africa is governed by various legal status as applied to the general forestry such as:

- National Environmental Management Act (No.107 of 1998) – under this section 24 (2), 24 (5), and 24D, the Minister has the authority to deem what activities are permissible and may commence based on their environmental impacts. This created the regulatory basis for Environmental Impacts Assessment (EIAs) which are applied to different activities (Ecoplanet, 2014). In Notice 2, activity 16, an EIA will be implemented where "The physical alteration of virgin soil for agriculture or afforestation for the purpose of commercial tree, timber or wood production of 100 hectares or more have taken place". Virgin soil is defined as soil that was not cultivated for the past 10 years.
- National Forests Act (No.84 of 1998), this Act lays out the framework for protection of vital forest resources in South Africa including indigenous forests. It also gives the Minister the authority to declare parks, indigenous forest and provide protection.
- National Water Act (No.36 of 1998) –makes provision for the regulation of water use, according to section 21, where water uses might need authorization from the Department of Water Affairs (DWA). Section 21 (d) of the act introduces water uses engaging in stream flow reduction activity (SFRA). Any activity can be declared as an SFRA if that activity is likely to reduce the availability of water in a watercourse e.g. commercial afforestation of deep rooted species like Eucalyptus.
- Bamboo is recognized as being a potentially important dry land water user, which could be declared as SFRA, alongside forestry and possibly other dry land crops, however, it is currently not classified as SFRA according to DWA.
- Conservation of Agricultural Resources Act (No.43 of 1983). The act covers invasive species within South Africa and how they should be handled by landowners. The amended regulations make provision for four groups: declared weeds (Category 1 plants), plant invaders (Category 2 and Category 3 plants) and indicators of bush encroachment.
- National Veld and Forest Fire Act (No.101 of 1998) – The act places a duty on landowners to build and maintain firebreaks where a veld fire can start to spread.
- Farm Feeds, Agricultural Remedies, and Stock Remedies (No. 36 of 1947). Section 3 of this Act requires that any fertilizer, agricultural remedy sterilizing plant used on the land need to be registered.
- Agricultural Pests Act (No.36 of 1983) – This act provides for measures whereby agricultural pests may be prevented and combatted from entering the country.

- Occupational Health and Safety Act (No. 181 of 1993) – The Occupational Health and Safety Act (OHSA) states that every employer shall provide, as far as reasonably practicable, a working environment that is safe and without risk to the health of its employees.
- Extension of Security of Tenure Act (No.67 of 1997) – The Act protects the rights of farm communities and farm dwellers.
- There are two propagation methods for plantation of bamboo namely, seed propagation and vegetative propagations also called cloning (Boschma and Kwant, 2013). In South Africa the most common method being used to create bamboo plantation is by vegetative methods where the hardened bamboo from tissue culture export from Asia, mainly India and China are planted in South Africa. Cloning or vegetative propagation is deemed laborious and is mainly done for tropical bamboos through the cutting of the rhizomes and branches (Boschma and Kwant, 2013).

The following methodology for the vegetative propagation of bamboo is used from the nursery to the field:

- Place the species in a pot under incubating green house production lab until it hardens into plugs;
- Water the plugs species for full first year before plantation;
- Prepare the plugs that are to be planted in bags under shade cloth;
- After 3 months prepare the soil for planting; and
- Planting within the September, October and November season is recommended .

A total of 13 bamboo species (Table 2-14) from the literature was selected from the 20 best list of growing species in the world to analyze the climatic conditions with the aim to compare which of the species will be suitable for South African conditions, particularly the Penge area where the piloting is expected to be conducted (http://bambooplantation.com/files/price-list.php 2017 Feb). According to the literature of bamboo based –agroforestry the enthopedology (knowledge on soil charectersitics from local farmers) and soil quality index together with climatic conditions of the pilot site plays very important (Nath, Rattan and Das ,2015).

From their paper they have combined the current scientific knowledge of soil classification based on physical ,chemical and biological properties as used by Granatstein and Bezdicek

,1992 and soil quality index with parameters like soil acidity, rooting depth ,soil organic carbon ,texture ,bulk density ,nutritents ,water holding capacity etc. being analysed as used by Doran and Parkin 1996 together with indigenous knowledge from local in the North East region of India called folk system . In the study the following conclusions were made on the soil quality suitable for bamboo in the Dargakona village , Cachar District , Assam ,North East India. The statistical data analalysis shows that the black soil locally called *kalo mati* is more productive for bamboo plantation followed by red soil (*lal mati*), stony soil (*pathal mati*) and sandy soil (*balu mati*) and that soil organic carbon and water holding capacity and total nitrogen are the most distinguishing parameters on the productivity of bamboo and local climate and indigenous knowledge of farmers plays a very important role in the sustainability and productivity of bamboo agroforestry (Nath,Rattal and Das, 2015).

Based on the study done by Nath *et al. 2*015 Table 2-14 below can be interpreted as follows based on the soil type classification for better clarification . The following descriptions can be compared as follows , rich soil can be compared with black soil (*kalo mati*-rich in soil organic carbon), medium soil can be compared with red soil (*lal mati*) and medium to poor soil associated with stony soil(*pathal mati*) and sandy soil (*balu mati*).

Table 2-14: Proposed bamboo suitable for planting under South African climatic conditions

Species Name	Soil type	Rainfall (mm)	Humidity	Min Temp ^{0}C	Environ mental Rehabilit ation	Rural Industries
Bambusa balcooa	Medium to rich	650-1000	Humid to dry tropics	26	High potential	High potential
Bambusa bambos	Poor to rich	300-1000	Humid-dry and semiarid	27	High potential	High potential
Bambusa blumeana	Poor to rich	300-1000	Humid-dry and semiarid	27	High potential	High potential
Bambusa vulgaris	Poor to rich	650-1000	Humid-dry and semiarid	27	Little	Little
Dendrocalamus asper	Rich	650-1000	Humid to dry tropics	23	High potential	High potential
Dendrocalamus giganteus	Rich	1000-1300	Humid Tropics	25	Medium	Little
Dendrocalamus latiflorus	Rich	1000-1300	Humid Tropics	25	High potential	High potential
Dendrocalamus strictus	Poor to medium	300	Dry -semi arid	24	High potential	High potential
Gigantochloa apus	Rich	1000-1300	Humid Tropics	27	Medium	Medium
Gigantochloa levis	Rich	1000-1300	Humid Tropics	32	High potential	Medium
Guadua angustifolia	Medium to rich	1000-1300	Humid Tropics	30	High potential	High potential
Phyllostachys edulis	Medium to rich	300	Temperate	0	High potential	High potential
Thyrsostachys siamensis	Medium	300	Dry tropics	0	High potential	High potential

2.13 Chapter Summary

It is against the data presented in the literature survey above that the current investigation is based and upon which the models used in this report are drawn. It was found in the literature that studies were conducted in South Africa on biomass conversion, mainly on biofuel energy, e.g. cassava and sugar cane. However, there is no specific literature available in South Africa on the economic potential of different bamboo plantation, and its energy prospective in the way it is structured in this research study. The literature available locally and related to bamboo is on the characterisation of bamboo as an energy source (Sarfos *et al.*, 2001; Bada *et al.*, 2014 and Bada *et al.*, 2015).

There are various legislations that are needed to be adhered to for successful plantation of bamboo as bamboo are alien species in South Africa. Looking elsewhere in the world, many techno-economic studies were undertaken mainly on some woody biomass such as poplar and different herbaceous biomass such as reeds, wheat, sugarcane, and cassava. It can be deduced that all the biomass cited in this literature survey show potential to be converted into useful energy by-products on technical merit. However, all these processes are not economically efficient by themselves; they need some external support based on policy measures and subsidies to be fully economical. It is based on the literature survey reported in this research report and data gathered from the fieldwork expedition that this investigation was grounded.

It can be summarised that the suitable bamboo that can grow in the Highveld region of South Africa, especially the proposed pilot area "Penge", based on the data presented on Table 2-14 above are *Dendrocalumus asper*, *Dentrocalumus strictus* and *Phyllostachys eduluis*. From the same table, it seems that *Bamboo balcooa* and others species are more suitable to be grown in the coastal areas of the country. Therefore, the model assumption in this study was based on the plantation of *Dendrocalumus asper/ Dendrocalumus strictus or Phyllostachys* eduluis as a pilot plantation in the Olifants River Basin in the Penge area.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The preceding chapter was a review of literature relevant to this study and some of the observations made during the study tour of some newly established plantations in the coastal areas of South Africa. This chapter discusses the research methodology used in evaluating the economic feasibility of growing bamboo plants on rehabilitated asbestos mine sites. The research approach and its appropriateness in addressing the research objectives and problem statement are all outlined in the report. This includes justification by the researcher on the choice of study site, the research technique applied and the data collection instruments used.

The bamboo plant was chosen for closer investigation because of its potential to grow rapidly and its ability to grow in nutritionally and biologically impoverished areas such as abandoned mine sites. The potential of bamboo to grow in such nutritionally impoverished areas, its ability to produce energy and to sequestrate $CO_{2,}$ once planted, were the major factors behind this study. The study and the associated techno-economic model utilized was conducted mainly with secondary data from the literature; the latter concerning bamboo production and energy generation around the world was used to close gaps in the modelling process. This study is intended to be used as a model to predict the economic viability and cost of establishing up a bamboo plantation and utilising bamboo as a feedstock in power generation. On that account, different assumptions were made to create a techno-economic scenario for assessing successful bamboo plantation on a rehabilitated abandoned mine for energy conversion purposes.

None of the bamboo species mentioned were planted on rehabilited mine sites in this study. For the purpose of the model, bamboo species and their growth factors as planted for rehabilitation purposes mainly in Asia, Indonesia and India have been used.

In this chapter it will be assumed that the general main factors affecting the financial outcome of any plantation according to Gerrand *et al.* (1993) are as follows:

- Management Regime;
- Site quality index;
- Discount rate;
- Royalties;

- Distance to market;
- Level of establishment and maintenance costs; and
- Treatment of land costs.

It has been mentioned that the interrelationship between the above factors determines whether or not, purely on economic grounds, plantations will be successful. It must be noted that not all these factors will be used in this study as some of them (e.g. distance to market, treatment of land costs and royalties) will be assumed to be zero in the model. Land, and other related compensations to land such as royalty will be provided free by State, as the intended pilot study is assumed to be taking place on public land owned by the State.

3.1.1. Management regime

The management regime, according to Gerrand *et al*. (1993) can be described by the main product which the plantation is intended to produce. In this study, the main product will be the quantity of biomass required to efficiently generate electricity and the amount of energy generated in KWhr or MWhr in the form of heat from bamboo feedstock once harvested using provided technology as quoted by Afrimine Solution and Greener Alternative Solutions (Pty) Ltd, respectively.

3.1.2. Site quality index

This entails comparison of various sites regimes based on land suitability for growing bamboo and this includes comparisons of climatic conditions, soil conditions of the region where the intended pilot study is envisaged and the project feasibility. A study has shown that in Limpopo a soyabeans plantation will yield 450000 to 500 000 tons per annum, which is equivalent to 2.5 to 3t/ha under dry land conditions (Rampedi, 2010). It is with this data in mind that a dry land within the Olifants river basin in Penge the same quantity of output in tonnes/ha is anticipated from bamboo plantation

3.1.3. Discount rate

According to Gerrand *et al.* (1993) the selection of an appropriate discount rate in a plantation is always problematic as this has a very large effect on the financial viability of the forestry operations. The forestry commission recommends discount rate of 8%, but this is deemed too high by other stakeholders involved in forestry plantation. The use of discount rate in managed natural forests and plantations is because of lack of active markets to quote prices for large plots and forests . South Africa and many other countries involved in managed forestration uses pre-tax discount rate ranging anything from 10-12% maximum.(PwC International Agriculture standard 41(IAS 41 review),2003)

3.1.4. Royalty rates

It is always a norm to pay royalty when working on forest land as per different government regimes and nations. In plantations it is always considered that the royalty increases with the quality of plantation. Although paying royalty is a norm on government land and in this case to avoid complexity royalty will be assumed as zero, as the land will be provided for free by Mintek as the implementing agency of DMR rehabilitating public land on behalf of the state.

3.1.5. Annual plantation maintenance costs

Annual plantation maintenance costs was assumed to be R12825.00 per ha base on the assumption calculation done in the appendix A of the model.

3.1.6. Treatment of land costs

The cost associated with the treatment of land is a major cost etsiamted R 8029 per ha and includes field preparation, ripping and hole spacing preparation (see Appendx A).

3.1.7. Distance to market

The distance to processing plant/market was assumed to be zero based on the fact that the biomass processing facility will be installed within 2km radius of the bamboo plantations.

3.2 Visited Bamboo pilot sites in the Western Cape Province and Kwazulu Natal

The data and information sourced from the two plantations stated above were used as part of the facts and assumptions made in developing a model to assess the economic potential of bamboo plantation in South Africa. A modified species of *Bambusa balcooa*, known as Beema bamboo was planted in coastal areas of North Durban, KwaZulu-Natal Province. However, different species of bamboo such as *Bambusa balcooa, Dendrocalamus asper* and *Phyllostachys aurea* are planted in Swellendam plantations, Western Cape Province Province. The soil at both sites was treated with fertilisers to improve its productivity. Mechanical site preparation included ploughing, disking, ripping and watering to remove weeds and promote root growth. Herbicides were also sprayed on the pilot site to control weeds. In this study assumptions were made based on the literature and data collected in Swellendam nursery plantation of Queen of Africa.

3.2.1. Climatic Conditions in Durban North and Swellendam

The climatic conditions in Durban and Swellendam are associated with coastal conditions with high humidity in Durban and cold temperatures in the Western Cape Province Province . Durban North experience 320 days sunshine a year, temperatures range from 16-25°C in winter, with an annual rainfall of 1 010 mm at an elevation of 8 meters along the latitude 30 degrees 57 seconds South and longitude 29 degrees 58 seconds East. During summer, temperatures range from 23-33°C. The warm Mozambique current flowing along the coast creates further north conditions to be subtropical. Swellendam in the Western Cape Province Province is classified as warm and temperate with the annual average temperatures of 18°C, an average rainfall of 564 mm and altitude of 42 m along the latitude 33 degrees 58 seconds South and longitude 18 degrees 36 seconds East.

3.2.2. Soil Conditions for the two sites visited

The soil conditions in Durban and Swellendam, according to the farmers, are of a poor quality as per verbal discussion. However, the quality of the soil was enhanced with fertilisers to allow the growth of bamboos. From the literature, asbestos mine sites are generally associated with soil which has low nitrogen and sulphur mineralisation rates, low phosphate availability and soil organic matter, poor soil structure, compacted subsoil, poor drainage and low water holding capacity (Weyers et al., 2010). As discussed in Chapter 2, the availability of water, suitable altitude, soil nutrients, and climatic conditions (annual rainfall and temperature) are the main critical natural factors that would influence the growth of bamboo plants.

3.2.3. Planting Methodology as Used in Durban and Swellendam Plantations

The model developed in this investigation was based on the assumption that bamboo plants were propagated using vegetative methods. The whole culms were provided with their roots lengthwise into the ground. Culm segments of the bamboo plants containing two or three nodes bearing healthy buds or branches were cut into pieces measuring approximately 25 cm each. The culms were then planted in rows that were 75 cm apart and at approximately 45º angle.

On another site of the pilot project, branch cuttings of the bamboo plant were buried into the ground. The propagated plants were watered to soak the soil around them and mulched with bark and organic material. The first sprouting and rooting appeared between three and five weeks later. After about three months, the bamboo plants had reproduced themselves laterally, thereby covering a much wider area than initially anticipated. The plants were watered and monitored over a period of one year, and measurements were taken on a weekly basis to monitor growth.

3.3 Penge pilot area chosen for plantation of Bamboo

Penge as reported in CSMI report study of 2008 falls within the cross border District municipality of Greater Sekhukhune land which was established in the year 2000. The district is inhabited by about a million people and it has been experiencing growth in the Tubatse area due to mining activities taking place, however the unemployment rate level is still high. According to the 2004/5 district integrated development plan report, the unemployment rate was estimated to be about 69%. In 2007 an investigation was concluded by Dr Steven Donohue of the University of Limpopo that Penge is highly populated with asbestos and therefore it was unfit for human habitation.

It's in this spirit that Mintek together with the Department of Mineral Resources has put effort in prioritising the area for rehabilitation, and this study is one of the many effort to contribute to many of the research solution suggested for Penge area in order to minimise the environmental impact associated with asbestos contamination, whilst on the other hand looking for sustainable solution to reduce the burden of unemployment as experienced by the area.

3.3.1. Climatic Conditions of Penge in Limpopo Province where the pilot site is envisaged

The pilot site being envisaged in the study is in the Penge area of Burgesrfort in Limpopo, although the climatic conditions of Penge are not studied in detail, but the area is close to Burgersfort and falls within the Olifants River Basin in which its environmental conditions have been studied extensively (FAO, 2004). According to (Bhalotra, 1987b; GOB–

MMRWA, 1991; Schulze, 1997 and Unganai, 1998), the climatic conditions of the Olifants River Basin is influenced by the air masses from the equatorial convergence zone, the subtropical eastern continental moist maritime to dry continental tropical and marine west Mediterranean. The basin is predominantly semi- arid, dry and hot with average rainfall in the central valley of 400mm-600mm (Köppen, 1918 and Rosenberg, 1999).

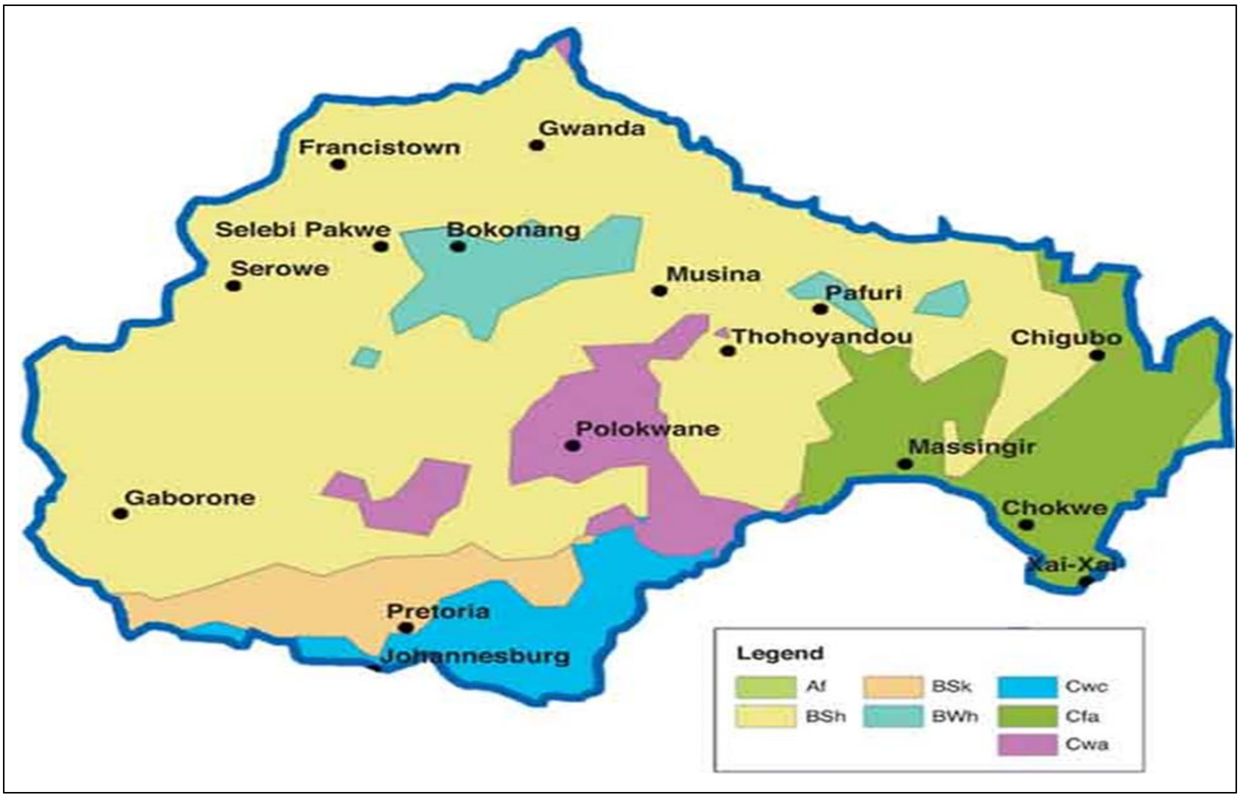

Figure 3-1. A locality map showing the Olifants River Basin

Penge area in Limpopo is in the Highveld with semi-arid conditions and an escarpment that experience sub–humid climate with an average temperature of 20 degrees Celsius in winter and 27 degrees Celsius in summer. The annual rainfall is about 400-600mm, and the bulk of it occurs in summer (Tshiala *et al*., 2011).

3.3.2. Soil Resources and Condition of Penge

The soil resources of an area are an important factor in managing the effects of drought and climate variability. Soil properties that relate to water storage (texture, soil depth and internal drainage) are particularly critical in semi-arid environments experiencing drought conditions.

Soils also reflect environmental changes, and monitoring such changes is important in assessing the impacts of land use. The soils in the Olifants River Basin may be categorized broadly into two main groups: (i) old soils formed in deeply weathered parent materials, influenced by earlier erosional surfaces; and (ii) relatively young soils, formed on the more recent erosional surfaces, or on alluvial deposits. Deeply weathered ancient soils occur mainly on the plateaus (Highveld) of South Africa and Zimbabwe, and in some protected areas of the escarpment zone.

The soils formed over a long period on the weathering mantle or saprolite, and developed under warm and humid climate conditions needed for intense chemical weathering. Younger and less weathered soils characterize the denuded hills and mountain ridges, the low veldt, the coastal plains of Mozambique, and also large parts of the higher plains within the Olifants River Basin where recent and subsequent erosion has removed the deeply weathered soils. Recent and subsequent climate conditions have not been conducive to strong weathering and new formation of saprolite in the eroded areas. This applies also to the highveldt; higher rainfall and higher temperatures than those occurring at present are required for progressive saprolite formation (FAO, 2004).

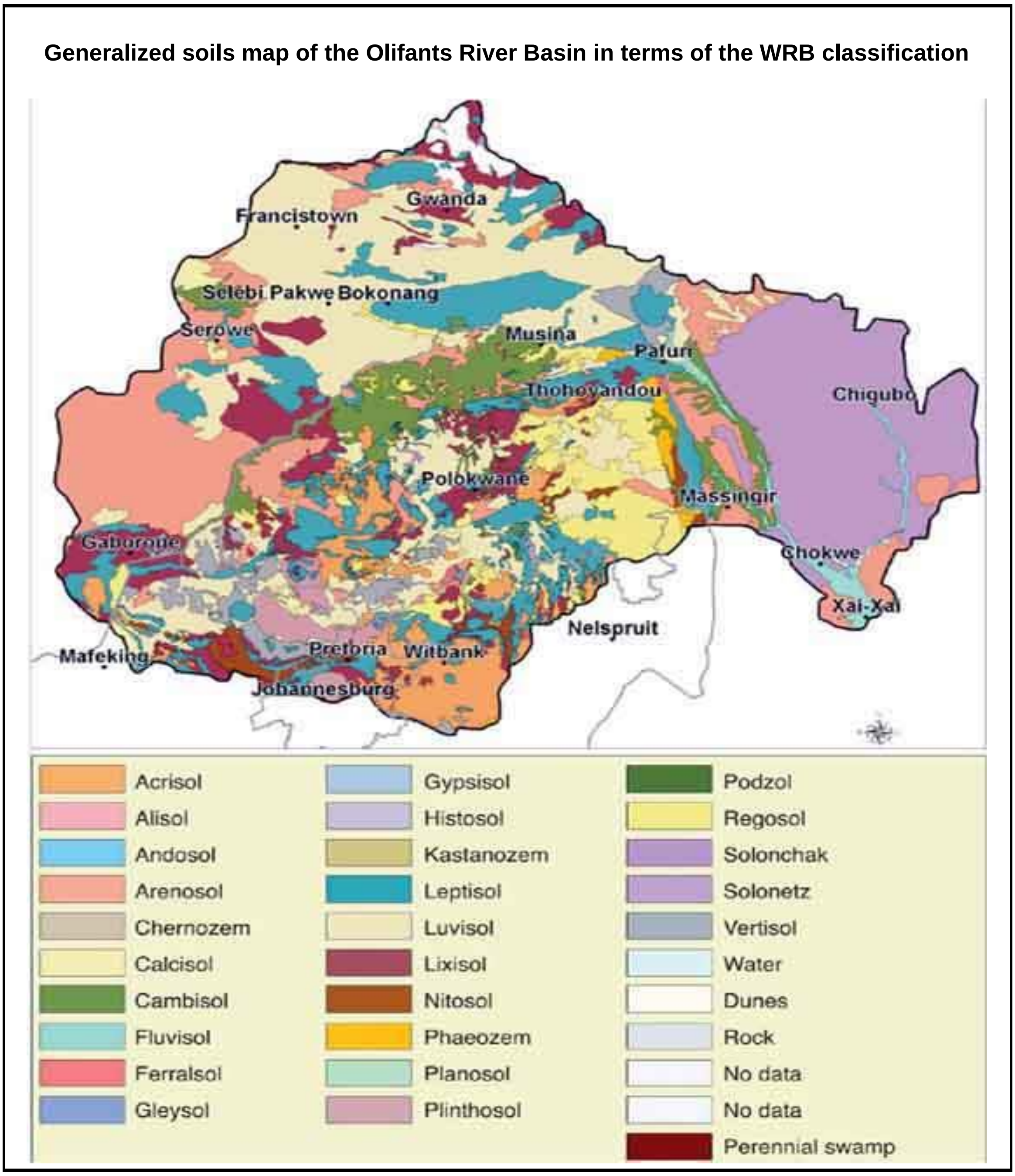

Figure 3-2: Generalized soil map of the Olifants River Basin

3.4 Development of the Financial Model

A financial model is a theoretical construct that represents economic processes by a set of variables which illustrates the logical and quantitative relationships between them. It is also a simplified description of reality that is designed to yield hypothesis about an economic behaviour that can be tested. It helps financial analysts and managers to isolate, sort out and demonstrate complicated chains of cause and effect relationships, illustrate complex processes, often but not always using mathematical and other quantitative techniques. Through the use of models, economists and financial analysts experiment with real data by producing different outcomes or scenarios from which a choice is then made.

Several types of investment appraisal methods such as payback period, accounting rate of return (ARR), internal rate of return (IRR), profitability index (PI) and net present value (NPV) can be used to assess the financial feasibility of an investment project. Although the NPV is the most commonly used approach for project evaluation by many firms (Volker et al., 2009) the technique used in this research is that of IRR. The IRR measure the rate at which benefits are realised following an intial capital investment and it can be thought of as the constant compound rate of return which is equivalent to the actual fluctuating rate of return over project lifetime (World Bank, 2003). IRR is also closely related to the NPV in that IRR is the rate of discount at which the NPV of the project is reduced to zero. The NPV measure the profitability of an investment and assess a project's expected return on investment. The NPV of an investment project reflects the degree to which its future cash inflows equals or exceeds the amount of investment capital required to fund it and future operating costs. It is the difference between the present value of future cash inflows and cash outflows in an investment project. The calculation of NPV takes into account the time value of money by compounding the discount rate (interest rate) over the duration of the project. When assessing multiple projects, corporates use NPV as a way of comparing the relative profitability of the projects and ensuring that the most lucrative projects are pursued. Projects that have a higher NPV are chosen since they are more profitable than projects with a lower NPV.

The following is the formula for calculating IRR :

Present value of cash flows – initial investment =0 OR

$$\left. \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \ldots \right] - \text{Initial Investment} = 0 \text{----------Equation 3.1}$$

Where;

CF_1= is the period one net cash inflow

CF_2 = is the period two net cash inflow

CF_3= is the period three net cash inflows

r = discount rate, and

The following is the formula for calculating NPV:

$$NPV = \sum_{t-1}^{r} \frac{C_t}{(1+r)^t} - C_0$$ --- Equation 3.2

Where;

C_t = net cash inflow during the period t

C_0 = initial investment costs

r = discount rate, and

t = number of time periods

A positive net present value indicates that the present value of the projected cash inflows or revenues of the project exceeds the present value of anticipated costs. Conversely an investment with a negative NPV will result in a loss, which means the present value of future cash inflows is lower than the present value of future cash outflows. In this investigation, the financial model developed based on the investment decision on the use of 50 kW combustion engine plant for generating power with bamboo as feedstock critically depends on the future of cash flows that are generated by the project, life span of the project and the discounting factor. Future cash flows will represent the revenues generated by the project, while the discounting factor represents the degree of uncertainty associated with these cash flows. The degree of uncertainty or risk in projects is represented by the project's cost of capital. The project lifespan represents the useful economic life of the project during which it will earn the owners a return on investment. The interaction of the three critical factors in investment decision making is illustrated in Figure 3-3 below.

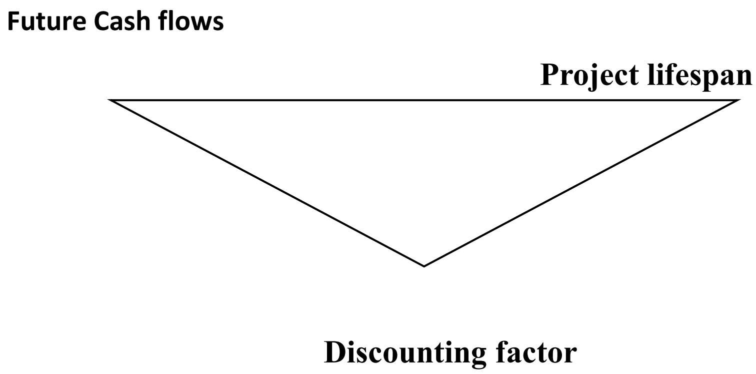

Figure 3-3: Factors in investment decision-making (McNeel, 2006)

3.5 Assumptions of the economic Model

The economic model developed in this study had two major components. The first block being the assumption costs associated with developing nursery plant and plantation of bamboo plant species (*Dendrocalamus asper /strictus*) on a 100 ha pilot rehabilitation land in Penge using data extrapolated from the Queen of Africa bamboo nursery and plantation gardens in Swellendam (See attached Appendix A, Table A1 and A2). The second block being capital expenditure related to the acquisition of the combustion plant with a capacity of 50 kW and also determining the quantity of biomass to be processed to yield usable amount of energy revenue inflows from electricity (See attached Appendix C).

The costs of transporting *Dendrocalumus Asper* from the Queen of Africa farm to the Penge pilot site in Limpopo were also incorporated into the model together with the maintenance costs, consumables and labour. Currently, it costs approximately R20 to transport a 50 kg bag of dry material over 1 000 kilometers in South Africa. Cash inflows in this model if developed would be assumed to be associated with the sales of electricity/heat, and 73 cents/ Kwhr was proposed as unit cost per kWh based on average unit in rural power figures in South Africa (Nkomo, 2005). The yield of the bamboo (biomass/ha) obtained in a year from the plantation along with the heat energy of the species was determined for a 50 kW combustion engine plant.

CHAPTER 4: ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

The previous chapter considered the research methodology employed in this study. This chapter presents research findings and discussion of results. The first part was based on research findings coming from primary data gathered from the pilot project on bamboo plantation in Swellendam and Durban and projecting them to fit in with the Penge area with its own conditions. The second part discusses and evaluates the economic potential of replicating the bamboo plant study to produce electricity. Secondary data on equipment prices and electricity prices as reported in the literatures were utilized in discussing the research results.

The secondary data used are applied in validating, augmenting and reinforcing the research findings from the pilot study on bamboo production and the financial model that was built to evaluate the economic feasibility of generating electricity from a 50kW combustion engine plant that uses biomass as feedstock materials. The discussion of the results also incorporated contributions from the academic literature and media publications on each concept being investigated. The main objective of this discussion was to establish common features and points of departure between what is practicable in the real world and academia.

4.1.1. Literature Survey and Site tour

Bamboo as a source of biomass was discussed in detail using a literature survey sourced worldwide. From this it is clear that little research was done in South Africa and Africa as a region with regard to use of bamboo biomass on mine rehabilitation and as a biomass feedstock for energy use. A vast study of other biomass, including bamboo as a source of biofuel was done mainly in the Indo-China regions, North America, South America and Europe. A literature survey of bamboo as a rehabilitation agent was performed primarily in India, with less focus on its suitability as an energy feedstock in those instances.

From a site tour perspective various pilot studies were proposed in South Africa on the plantation of bamboo, especially around the coastal regions of the country as many of the bamboo species were deemed to be suitable to thrive only along the coastal region of South Africa. However, there are few species that are spread over the Highveld, but many of these species, including those planted in the coastal area are not indigenous to South Africa. Many of the South African plantation are only restricted to nursery stage and a few sites except in Kwazulu Natal where the project is sponsored by the Industrial Development Corporation (IDC) a meaningful bamboo plantating was done.

It is clear from the available literatures in the public domain that bamboo should be able to grow in the Highveld region of South Africa based on the similarity in the region physioclimatic requirements conditions in which bamboo species grows throughout the world. In this study, only three species were found suitable to be suitable for South African Highveld conditions, namely *Dendrocalumus asper, Dendrocalumus strictus and Phyllotsachys edulis.* The literature also made it clear that the chosen site of Penge in Limpopo has the physiographic conditions that are suitable for plantations of the above three bamboo species. However, the economic model is based on *Dendrocalumus asper* and therefore the assumption is made that its energy characteristics are similar to other species planted elsewhere in the regions of South Africa example being *Bambusa balcooa* which thrives in the nurseries along the visited coastal regions of South Africa i.e. Northern Kwazulu Natal and Western Cape Province, Swellendam area.

4.2 Management Regimes

In this method various aspects of bamboo plantations were analysed based on various main products and assumptions, such as bamboo plantation costs, bamboo estimated harvest yield in tonnes and energy output based on the chosen technology and type of species "*Dendrocalumus asper".*

4.2.1. Bamboo Plantation Costs

The major cost drivers for bamboo production on an abandoned mine site, in this research were land preparation, planting, watering and irrigation, harvesting, and bamboo preparation for further processing. It is assumed that the initial production will be associated with the preparation of the nursery plantation using vegetative propagation as imported seeds from tissue culture research institute mainly from Eastern regions namely China and India. In this model, a total of 100 hectares of land was estimated to be put under bamboo plantation with an expected yield of approximately 14t/ha per annum during the 5th year of harvesting based on assumptions of detail model calculations in Table A2 of Appendix A. It is estimated that a total of 14t/ha of bamboo biomass will be produced in the first 5th year of production stabilizing to 47t/ha in the 7th year of harvesting and in turn, be used as feedstocks for the 50KW combustion unit as provided by Afrimine Solutions (Pty)Ltd or Gasifier unit quoted by Greener Alternative Solutions(Pty) Ltd.

The pilot study revealed that approximately 40% of bamboo production costs were incurred during land preparation, while watering, harvesting, and preparation of the bamboo plants accounted for the remaining 60% of bamboo production costs. If this pilot study is replicated on a large scale, mechanized preparation of land, using tractors and the disc that is powered by diesel will be a key driver for establishing a bamboo plantation. The harvesting, crushing and milling of bamboo plants will also form a significant part of the production costs.

Assuming the sale price of harvested bamboo is **R1 765.20** per tonne as per the model in Appendix A (Table A2):

- The bamboo plantation will start to be profitable in year 5 of harvesting to a value of **R1 034 424** (R1.03 million) after incurring a full loss of;
  (R80 506 + R 1 814 173 + R 995 643 + R620 043) = **R3 510 365** (or R3.5 million) in the first 4 years before harvesting as per Appendix A (Table A2).

- From table A2, the capital costs of **R12 310 820** (R12.3 million) is associated with the above 100 ha plantation, and the overall plantation is profitable to recover capital costs spent over 12 years and it sits on the positive net of R38 722 647 – R12 310 820 =
  R26 411 827 (R26.4 million).

- Based on the model assumption the capex costs will be paid off in the 7th year of harvesting at (R1 451 860 + R 3 606 3341 + R 6 286 302) = **R17 087 805** (or 17.08 million).

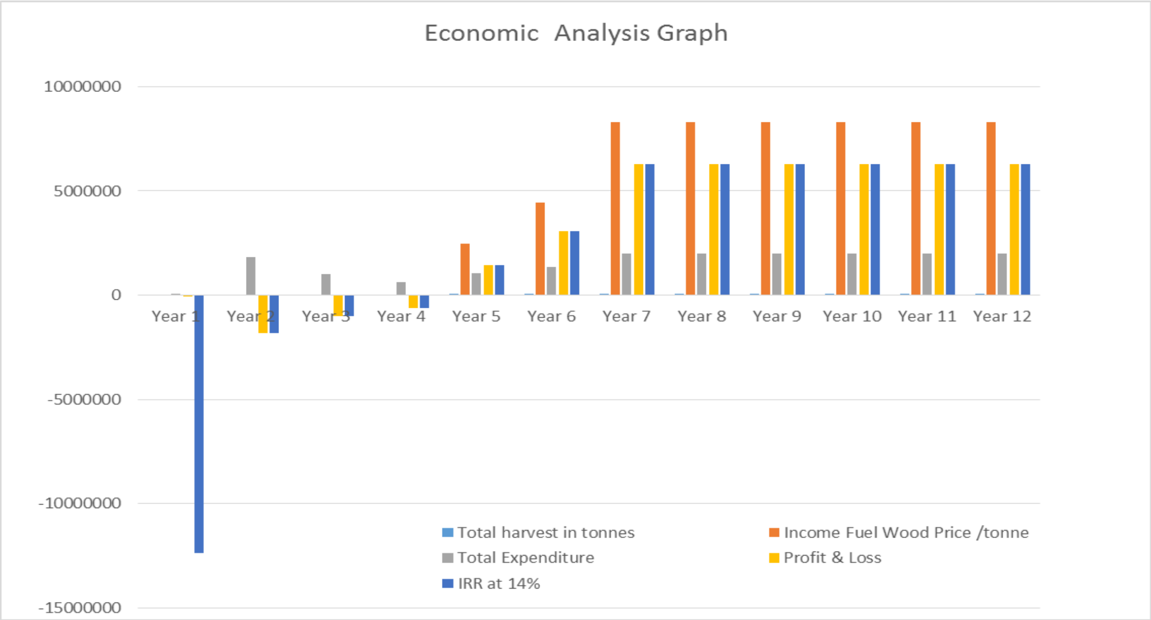

Figure 4.1: IRR, Expenditure and Profitability

- From the Figure 4.1 and Table A2 in the appendix shows that the project will only be profitable from the 5th year of production and at the discout rate of 14% which is high than the normal 8% accepted in literature the IRR is positive from the 5th year and avarge about R2.2 million over 12 years life of operation.

4.2.2. Bamboo feedstock technology cost model

The quantity in tonnes/ha of *Dendrocalamus asper* needed from the Penge pilot plantation sites to run a combustion engine of 50 kW capacity efficiently was determined from the second stage of the economic model.

Based on the assumption made under Appendix B, the amount of the *Dendrocalamus asper* with calorific value of 17.81 MJ/kg required to run a 50 kW Combuster;

- **0.0312 tons/hour,** which is equivalent to (0.0312*24) = **0.75 tons/day**, and (0.75*365) = **273 tons/annum**.

Still based on the same assumptions from Appendix B;

- 0.0312 tons/hr of biomass will yield 1 kWhr of electricity from a 50 kW Combuster provided by Afrimine Solutions Pty Ltd.

- Which is equivalent to 0.75/0.0312 = 24 kW/day = 24*365 = 8760 kW/annum.

Therefore, electricity yield in the 5th year of harvesting with a biomass quantity of 14t/ha/annum will be;

- (8760 kW/annum *14t/ha/annum) /273 t/ha/annum = 449 kW/annum.

Assuming electricity sale price of 73 cents/kWhr based on rural industrial power price, the total electricity sales generated in 5th year of generation will be;

- (73*24*365 * 449) = 11963605 cents/annum = 11963605/100 = R119636/ 1000 = R 119.6361 = R 0.1 million /t/ha/annum.

Although the costs of running the combuster are very important to determine the efficiency and profitability of the technology after the initial installation costs of about R4 million in this research they were ignored because evaluation or assessment of efficiency of technology be used was not part of this research report.

4.3 Capital Expenditure Costs

Based on the information from the original equipment manufacturer Afrimine Solutions Pty is estimated as R4.3 million, as the total capex for the installation of technology by the supplier. In this study, reference was only made to the 50 kW Combuster and therefore, the Capex considered was R4.3 million.

4.4 Operating and Maintenance Costs

Operating and maintenance costs include variable costs such as labour, water and rates, waste disposal, feedstock materials, insurance, depreciation, taxation, and transportation for which the details were not investigated in this report.

4.5 Cash Inflows

Cash inflows are assumed to comprise of sales revenues that are generated from the direct selling of biomass wood in price per tonne and the energy generated from 50 kW combustion engine plant. Cash inflows from the combustion engine are functionally related to the electricity price, generation capacity of the plant and hours of operation. The unit price of electricity is assumed to be a critical driver of profitability for the 50 kW combustion engine plant and has significant impacts on the NPV. However, it must be noted that in this study, a detail, sensitivity analysis based on cash flows from electricity revenue analysis was not done to ascertain the profitability and workability of biomass energy feedstock model in this report. Electricity tariffs in South Africa are widely viewed to be significantly below production cost, although this view is subject to contestation from the industry and ordinary consumers. State power utility, Eskom’s Multi-Year Electricity Pricing Mechanism anticipates that electricity prices will be increased by an average of 25% until the tariffs are reflective of production costs.

4.6 Critical Success Factors for any Power Generation Project Using Biomass

Three critical success factors of the power generation project using biomass need to be taken into account. These success factors are discussed below:

4.6.1. Security of supply of feedstock materials

Security of supply of feedstock materials is critical to the profitability and success of the 50 kW combustion engine plant. Secure and consistent supply of feedstock will ensure that the biomass combustion engine plant operates at optimum capacity and that there are no plant downtimes that will adversely impact on electricity sales and profitability of the project. Currently, there are very few commercial bamboo plantations in South Africa, and this may adversely affect the availability of biomass materials as feedstock for the 50 kW combustion engine plant. In this report the estimated cost of planting bamboo and the yield of bamboo biomass was calculated assuming the conditions are deemed cost effective for piloting based on calculations done in 4.2.1 above.

4.6.2. Government support in biomass production and electricity marketing

Although many biomass projects like this in many country are only successful with government subsidies and normally electrification in South Africa is highly supported by government and it is imperative that the projects need to be financially viable to depend less on government subsidies as the country have many other social priority to address and therefore private funding will be ideal for this project.

4.6.3. Project financing

The unavailability of funding is widely seen as a major obstacle to the development and commercialisation of bioenergy generation technologies. The availability and structure of project financing can have a significant effect on the financial viability of the combustion power plant largely due to higher investment costs. The availability of concessionary funding from government-owned development finance institutions such as the IDC at a lower interest rate would have a significant impact on the financial viability of the combustion power plant.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1: Introduction

This chapter presents the conclusions reached during the course of this investigation. These have led to recommendations for policymakers on the feasibility of growing bamboo plants on rehabilitated mine site such as asbestos mine sites, and in turn, the use of bamboo plants as feedstock material for electricity generation using a 50 kW combustion engine plant. The findings in this report could also be adopted as a source of creating economic opportunities for communities living close to the abandoned mine sites.

More specifically, the conclusions may be listed as follows:

1. The information provided from the literature has ascertained that bamboo plants can be grown on abandoned mine sites with low soil organic matter and essential soil nutrients as shown by case studies in India on ravine systems and other related papers. In addition, the experiences in India proved that bamboo controlled soil errosion.

2. The information obtained from the Western Cape Province(Swellendam district) and KwaZulu-Natal Province (Northen KwaZulu Natal region) bamboo plantations were found to be suitable for planting bamboo based on their climatic conditions including those that are "warm and humid" and non-arable land.

3. Based on the physioclimatic conditions of the Penge pilot site located within the Olifants River Basin, it is concluded that there are only three bamboo species that can thrive in that area and on the climatic conditions there, namely; *Dendrocalamus asper, Dendrocalamus strictus and Phyllostachys edulis*.

4. Bamboo has many potential uses including in construction, chemicals and energy , however, based on the detailed literature studies undertaken by other researchers on bamboo as an energy product or co-firing agent, its maximum energy content can only be used after torrefaction. This process also reduces the high alkali content associated with biomass, but the cost associated with the process was not considered in this study.

5. Based upon the model as derived in this research, the quantity of *Dendrocalamus asper* biomass of 14t/ha/yr in the 5th year of harvesting and increasing to 47 tonnes /ha/yr in 7th year is expected to be produced on potential rehabilitated pilot mine sites in South Africa. The conditions best suited for their growth (soil, nutrient composition, altitude, temperature, and average rainfall) has been predicted based on the data collected from Swellendam, Northern Kwazulu Natal and throughout reviewed literature in this study. According to the literature, species yielding more than 30 tonnes/ha/yr are considered highly productive.

6. A preliminary financial calculation has been developed that evaluates the economic feasibility of establishing a 50 kW power combustion engine plant that uses biomass as feedstock materials. This estimates sales revenue of about R 0.1 million from biomass feedstock produced in the 5th year of harvesting.

7. Based upon experiences quoted in literature and from the current model for the plantation, the project would be able to create both permanent and seasonal jobs for the local communities in that bamboo material can be processed successfully for further downstream broader economic benefits such as energy generation and, based on experience from elsewhere, for manufacturing of a wide variety of products.

8. Over and above the current conclusions, a major national benefit may be achieved. namely, the reduction of the greenhouse gas emission, CO_2. Given the current concern over climate change and the role of CO_2 arising from coal combustion in power generation, bamboo could have a major role to play by providing clean energy. This occurs when bamboo biomass is co-fired with coal in boilers to achieve the same heat output. Such co-firing results in the reduction of coal in the energy mix which in turn reduces coal-sourced CO_2 emissions. , also bamboo absorbs CO2 as the growing plants are a sink for CO_2 in the photosynthetic process. Literature has proved the quantity of CO_2 absorbed by bamboo. In this manner, the growth of bamboo for the production of biomass may well become South Africa's main mitigation method for the reduction of CO_2 emission in future.

9. According to article written by green peace in 2012 titled "The true cost of coal in South Africa –paying the price of coal addiction'', 4800 MW power sation like

Kusile produces 37 million tonnes of CO_2 per annum and from the above calculation 14t/ha bamboo feestock in fith year will produce 8760 KW (8.76 MW) which is equivalent to 0.067 million tones of CO_2

5.2 Recommendations

Based on the work undertaken thus far, it is strongly believed that further research should be undertaken in the following areas:

1. The growth rate patterns of different species of bamboo should be undertaken at full scale on different rehabilitated mine sites in the country to establish variability and adaptability relative to soil and climatic conditions. This would include different geographical areas, different rehabilitated mine sites (and soils) and different climatic conditions.

2. The use of acid mine drainage (AMD) water should be tested on one or more mine sites to establish which would be more beneficial for the growth of *Dendrocalamus asper*. An alternative type of research would be to see whether *Bambusa balcooa* would act as a "cleaning agent" by trapping some of the elements in AMD water.

3. The roots of *Bambusa balcooa* as obtained from one or more mine sites should be tested for heavy metal element uptake and whether such elements can be extracted using hydrometallurgical or pyrometallurgical methods.

4. *Bambusa balcooa* should be tested for its rate of CO_2 adsorption in order to rank its applicability as a CO_2 sink for low carbon use in combustion and gasification.

5. More detail financial model analysis should be conducted to ascertain the robustness of financial feasibility of processing bamboo for power generations and as co-firing fuel and doing detail, sensitivity analysis on electricity sale price, capex, opex and their impact on NPV and IRR.

REFERENCE LIST

1. Alexander, M.J. The long-term effect of Eucalyptus on Tin mine spoil and its implication for reclamation, *Landscape Urban Plan*, vol. 17, pp. 47-60, 1989.
2. Aveling, C. Notes on the golden monkey, Cercopithecus-mitis-kandti, of the Virunga Volcanos, Rwanda. *African Journal of Ecology,* vol. 22, pp. 63-64, 1984.
3. Bada S.O, Falcon, R.M.S and Falcon, L.M. Investigation of combustion and co-combustion characteristics of raw and thermal treated Bamboo with thermal gravimetric analysis. *Thermochim Acta*, vol. 589, pp. 207-221, 2014.
4. Bada, S.O, Falcon, R.M.S and Falcon, L.M. Characterisation and co-firing potential of a high ash coal. *Fuel,* vol. 151, pp. 130-138, 2015.
5. Bamboo Species Reference Table. http://bambooplantation.com/files/price_list.php. Downloaded 2017 February 02.
6. Banik, R.L. A short note on the flowering of *Dendrocalamus strictus* Nees. (La thibansh) in Chittagong Short communications. *Bano Biggyan Patrika*, vol. 10, no. 1-2, pp. 94- 96, 1981.
7. Banik, R.L. and Alam,M.K. A note on the flowering of *Bambusa balcooa Roxb*. *Bano Biggyan Patrika,* vol. 16, no. 1&2, pp.25-29, 1987.
8. Banik, R.L. Flowering in biajja bansh (*Bambusa vulgaris*). Letter to the editor, *Bano Biggyan Patrika,* vol. 8, no. 1&2, pp. 90-91, 1979.
9. Banik, R.L. Macropropagation of bamboos by prerooted and prerhizomed branch cuttings, *Bano Biggyan Patrika,* vol. 13, no. 1-2, pp. 67-73, 1984.
10. Banik, R.L. Observations on special features of flower136 in some bamboo species of Bangladesh. In., Higuchi, T. (ed.), *Bamboo Production and Utilization*, IUFRO, pp.56-60, 1986.
11. Banik, R.L. Propagation of bamboos by clonal methods and by seeds. In, G. Lessard and A. Choumard (eds.), *Bamboo Research in Asia*, IDRC, pp. 139-150, 1980.
12. Banik, R.L. Seed germination of some bamboo species. *Indian For,* vol. 113, pp. 578-586, 1987b.
13. Banik, R.L. Techniques of bamboo propagation with special reference to prerooted and prerhizomed branch cuttings and tissue culture. In A.N. Rao, G. Dhanaranjan and C.B. Sastry, *Recent Research on Bamboos*, pp.160-169, 1987a.
14. BEC (Biomass Energy Centre). *Forestry Research UK* ,2006. www.biomassenergy centre .org.uk, [Accessed 17 June 2017].

15. Ben-zhi, Z, Ma-oyi, F, Zheng-cai., Jin-Zhong, X and Xiao-sheng, Y. Ecological functions of bamboo forest: Research and Application. *Journal of Forestry Researc*h, 2005.

16. Bhalotra, Y.P.R. Climate of Botswana. *Part II: elements of climate. Gaborone*, Dept. Met. Services,1987b.

17. Bhatt, B.P, Singh, K and Singh, A "Nutritional values of some commercial edible bamboo species of the North Eastern Himalayan region, India," Journal of Bamboo and Rattan, vol. 4, no. 2, pp. 111–124, 2005

18. Bitariho, R. and Mosango, M. Abundance, distribution, utilisation and conservation of Sinarundinaria alpina in Bwindi and Mgahinga Forest National. Parks, South West Uganda. *Ethnobotany Research Applications* 3, 191-200. Casella, 2005.

19. Boden, T.A, Marland, G and Andres, R.J. Global, Regional, and National Fossil-Fuel CO2 Emission. Carbon Dioxide Information Analysis Centre, Oak Ridge *National Laboratory, U.S. Department of Energy*, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001, 2011.

20. Borman,G,Von Maltitz,G,Tiwari, S and Scholes.Modelling the economic returns to labour for Jatropha cultivation in Southern Africa and India at different local prices , University of Witwatersrand paper ,Department of Environmental Science,2013.

21. Capareda, S.C. Biomass energy conversion, sustainable growth and application in renewable energy sources, chapter 10, *Texas A&M University USA*, 2011.

22. Centre for Sustainability in Mining and Industry (CSMI). The socioeconomic aspects of mine closure and sustainable development, literature overview and lessons for socioeconomic aspects of closure,University of Witwatersrand, Johannesburg, report 1 2010.

23. Chapman, G.P. The biology of grasses. Department of Biochemistry and Biological Sciences, Wye College, University of London, U.K. CAB, 1996.

24. Chen, X, Zhang, X, Zhang, Y, Booth, T and He, X .Changes of carbon stocks in bamboo stands in China during 100 years. *Forest Ecology and Management,* vol. 258, no. 7, pp. 1489-1585, 2009.

25. Claassens, S. Measuring rehabilitation success of coal mining disturbed areas: A spatial and temporal investigation into the use of soil microbial properties as assessment criteria, PhD thesis, North-West University, Potchefstroom, 125p, 2007.

26. Coaltech report 7.8.5. The Socio-Economic Aspects of Mine Closure and Sustainable Development, Literature overview and lessons for Socio-Economic Aspects of Closure, report 1 of 2, 2010.

27. Coaltech. Guidelines for the Rehabilitation of Mined Land. Chamber of Mines of South Africa, 2007.

28. Constitution of the Republic of South Africa. No. 108 of 1996, 1996.

29. Coombes, A. Three minerals, three epidemics, text of talk given by Anthony Coombes at John Pickering Partners attorney, Manchester, 27th of November 2002.

30. CSMI. The Future of Penge. Prospects for People and the Environment. Project Report and Guidelines. Asbestos Relief Trust. [CitedMay2009]; Avaialble from www.asbestostrust.co.za/ documents/ Penge_Report.pdf, 2008.

31. Daza Montano, C.M., Pels, J.R., Fryda, L.E and Zwart, R.W.R. Evaluation of Torrefied Bamboo for Sustainable Bioenergy Production. *9th Bamboo Congress, Belgium,* 10-15 April 2012.

32. DEAT (The Department of Environmental Affairs and Tourism). The National State of the Environment Report for South Africa [Cited February 2009], 2009.

33. DME (Department of Minerals and Energy). Mineral Act. No. 50 of 1991 (Pros, 123dd.20.12.1991) as amended by Act 103/1993 w.e.f.1/9/93 Proc.75/1993.

34. DMR (Department of Mineral Resource). Progress on the management and rehabilitation of Derelict and Ownerless mines, 2014[Unpublished presentation].

35. DOE (Department of Energy). State of Renewable Energy in South Africa, 2015. Available at: http://www.gov.za/sites/www.gov.za/files/State%20of%20Renewable%20Energy%20in%20South%20Africa_s.pdf. [Accessed 13 June 2016].

36. Ecoplanetbamboo Southern Africa.Land restoration with Bamboo Eastern Cape South Africa, June 2014.

37. El Bassam, N. Energy Plant Species: Their use and impact on environment and development, James and James, London. vol. 321, pp. 21, 1998.

38. Eleri, A.I. and Eleri, E.O. Prospects for Africa – Rethinking Biomass Energy in Sub-Sahara Africa Energy and the Millennium Development Goals, 2009.

39. FAO, FAO Forestry Department, Unified Bioenergy Terminology (UBET). FAO Corporate Document Repository. 2005. Available at http://www.fao.org.

40. FAO. Drought Impact Mitigation and prevention in the Olifants River Basin. FAO subregional office for Southern and East Africa Harare, 2004,1960, FAO, Rome.

41. Fairall Mary-Ann of Bamboo for African Programme. www.trees.co.za/bamboo-symposium a-exhibition.html. East London 11-12 August 2011 [accessed 2016 June 17].

42. Farrelly, D. The book of bamboo. Sierra Club Books, San Francisco, California, 1984.

43. Filho, A.P. and Badr, O. Biomass resources for energy in North-Eastern Brazil, *Journal of Applied Energy,* vol. 77, no. 1, pp. 51-57, 2004.

44. Fourie, A, and Brent, A.C.A. Project-based Mine Closure Model (MCM) for sustainable asset life cycle management, *Journal of Cleaner Production*, vol. 14, pp. 1085-1095, 2006.

45. Gandure, S., Walker,S and Botha, J.J. Farmers perception of adaptation to climate change and water stress in a South African rural community, *Environmental Development*, vol. 5, pp. 39-53, 2013.

46. Gerrand, A, Prydon, R and Fenn, G. A Financial Evaluation of Eucalypt Plantations in Tasmania. Forestry Commision, *Tasmania, Queensland Forest Service*, October 1993.

47. Goldbatt, A. Agriculture: Facts and Trends in South Africa, 2013.

48. Greenpeace.The true cost of coal in South Africa paying the price of coal addiction , 2012.

49. Grosser, D. and W. Liese. On the anatomy of Asian bamboos, with special reference to their vascular bundles. *Wood Science .Technology*, vol. 5, pp. 290-312, 1971.

50. Grundmann,P,, Luckhaus, C, Heirmann, M., Hellebrand,H.J and Jacobs,H .Techno-economic evaluation of biomass conversion routes for Power generation, in particular via gasification and fermentation: Results from a feasibility study in Northeast Europe, 2004.

51. Hammett, A.L, Youngs, R.L, Sun, X.F, and Chandra, M. Non-wood fiber as an alternative to wood fiber in China's pulp and paper industry, *Holzforschung*, vol. 55, pp. 219-224, 2001.

52. Harris, J.A. Measurements of the soil microbial community for estimating the success of restoration, *Euroupe Journal of Soil Science Society* , vol. 54, pp. 801-808, 2003.

53. Hart, H.P. Asbestos in South Africa. *J.S.Afri.inst.Min.Metall*,vol.88, no.6 J, pp 185-198, June 1998.

54. Holman, J. Asbestos still a persistent problem in South Africa, http://www.engineeringnews, 2008.

55. Hossner, L.R and Hons, F.M. Reclamation of mine tailings and determining viability of establishing vegetation, 1992.

56. Howling, G.E. Asbestos, London, Imperial Institute, pp. 88, 1937.

57. Human Research Council Report on Poverty in South Africa, 2014.

58. Hunter, I.R. Bamboo resources, uses and trade: The Future? Journal of Bamboo and Rattan, vol. 2, no. 4, pp. 319-326, 2003.

59. International Energy Agency (IEA), Africa Energy Outlook, A focus on Energy Prospect in Sub-Saharan Africa , World Outlook Special Report, 2014.

60. International Network for Bamboo and Rattan (INBAR), Constraints to production of Bamboo and Rattan, Technical Report No. 5, 1992.

61. Kazan-Allen, L. Environmental asbestos fallout in Asia and Africa. International Bam Asbestos Secretariat [Cited May 2009], 2006.

62. Kobbing, J.F, Patuzzi, F, Baratier, M., Beckmann, V, Thevs, N and Zerbe, S. Economic evaluation of common reed potential for energy production: A case study in Wuliangsuhai Lake (inner Mongolia, China). *Biomass and Bioenergy,* vol. 70, pp. 315-329, 2014.

63. Kohler, M.R.A.R. The Economic Impact of Rising Energy Prices: A Constraint of South Africa `s Growth and Poverty Reduction Opportunities, Conference Paper University of KwaZulu Natal, 2006.

64. Köppen, W. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahresverlauf. Petermans Mitteilungen 64, 1918.

65. Koren, G. Windmill wings from Bamboo.https://gijsbertkoren.worldpress.com [accessed 2016 June 17].

66. Kurz, S. Bamboo and its uses. *Indian Forum* , vol. 1, pp. 219-269, 355-362, 1976.

67. Lakkad, S.C. and J.M. Patel. Mechanical properties of bamboo, a natural composite, *Fiber Science Technology,* vol. 14, pp. 319-322, 1980.

68. Landu, L. and Mashai P. Bamboo Potential for Mine Rehabilitation and Local economic development in South Africa, *Mintek Internal Report*, 2011.

69. Lee, A.W.C., B. Xuesong and N.P. Perry. Selected physical and mechanical properties of giant timber bamboo grown in South Carolina. *Forest Prod.J.,* vol. 44, no. 9, pp.40-46, 1994.

70. Lewandowski. I, Weger.J, van Hooijdonk.A, Havlickova.K, van Dam.J and Faaij.A .The potential biomass for energy production in the Czech Republic, Journal of Biomass and Bioenergy, vol. 30, pp. 405-421, 2006.

71. Li, M.S. Ecological restoration of mineland with particular reference to the metalliferous mine wasteland in China: A review of research and practice, *Science of the Total Environmen*t, vol. 357, no. 1-3, 2006.

72. Liton, M.R.I, Sadekin, Md.N and Muzib, Md.M. Micro-Credit as a Tool for Poverty Reduction in Bangladesh, *Journal of Sustainable Development* vol.5,No 25, 2014.

73. Lobovikov, M., S. Paudel, M. Piazza, H. Ren and J. Wu. World bamboo resource: A hematic study prepared in the framework of the Global Forest Resources Assessment 2005. *Food and Agriculture Organisation of the United Nations*, 2007.

74. McClure, F.A. and Durand, F.M. Propagation studies (with bamboo). Report of Federal Experiment Station, Puerto Rico, 1951.

75. McClure, F.A. and Kennard,W.C. Propagation of bamboo by whole-culm cuttings. *Proc. Am. Soc. Hortic. Sci.*, vol. 65, pp. 283-288, 1955.

76. McClure, F.A. The bamboos: A fresh perspective, Harvard University Press, Cambridge, Mass, 1966.

77. McNeel, R.W. Beating the stock market: Basic rules and attitudes for anyone who hopes to speculate successfully, 2006. Published.

78. Meyer, D.R. Nutritional problems associated with the establishment of vegetation on tailings from an asbestos mine. Environmental Pollution (Series A) 23: 287-298. 1980

79. Mineral and Development Resources Development Bill (Amendment of MPRDA Act 2002).

80. Mineral and Petroleum Resources Development Act No. 28 of 2002. Pretoria: Government Press. 2003. Available at http://www.nwu.ac.za/cem/conferencepapers.

81. Mintek Internal Progress Quartely Reports on Rehabilitation of Asbestos Mines, 2013.

82. Modi, V, S. McDade, D. Lallement, and Saghir, J. Energy and the Millennium Development Goals. New York: Energy Sector Management Assistance Programme, United Nations Development Programme, UN Millennium Project, and World Bank, 2006.

83. Molini, A.E. and Irizarry, J.G. Bamboo as a renewable energy resource. *In: Proceedings of the First Pan American Congress on Energy and Second National Conference on Renewable Energy Technologie*s, 1-7 August 1982, San Juan, Puerto Rico. Report.

84. Moore, T. Harvesting the Benefits of Biomass. EPRI Journal, pp. 16-25, May/June 1996.

85. Muthukumar, T. and Udaiyan, K. Growth of nursery-grown bamboo inoculated with arbuscular mycorrhizal fungi and plant growth promoting rhizobacteria in two tropical soil types with and without fertilizer application, Department of Botany, Microbiology Laboratory, Bharathiar University, Coimbatore 641 046, Tamil Nadu, India, 2005.

86. Naidoo, B. Outlawed asbestos leaves trail of death, suffering, claims and mining shame. 2008. Available at http://www.miningweekly.com.

87. Nath, A.J., Das,A.K and Das,G. Phenology and culm growth of *Bambusa cacharensi*s Majumdar in Barak Valley, Assam, North-East India, vol. 18, no. 1, pp. 19-23, 2004.

88. Nath, A.J.,Lal Rand G. Das,A.K. Ethnopedology and soil quality of bamboo(*Bambusa* sp.) based agroforestry system,*science of the total environment* 521-522(2015)372-379,2015.

89. National Environmental Management Act 107 of 1998.

90. Nedlac.org.za/…/10/Asbestos_November 2002.pdf partially unpublished report.The Socio-Economic Impact of Phasing out Asbestos in South Africa, website accessed April 2017.

91. Nel, J. Article on DMR has poor track record of compliance monitoring: Joint submission, 2006. Parliament of South Africa 2006.

92. Nienow, S, K.T, McNamara, A, Gillespie, R and Preckel, P.V. A model for the Economic Evaluation of Plantation Biomass Production for Co-firing with Coal in Electricity Production, *Agricultural and Resource Economics Review*, pp. 106-123, 1999.

93. Nkomo, J.C. Energy and economic development: Challenge for South Africa, Journal of Energy in South Africa, vol. 16, no. 3, August 2005.

94. Nsanganwimana, F., Pourrut, B., Mench., M.and Douay, F. Suitability of Miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services, *A Review Journal of Environmental Management*, vol. 143, pp. 123-134, 2014.

95. OECD (2013). OECD Economic surveys: South Africa 2013, OECD publishing.

96. Okudoh, V., Trois ,C., Workneh,T and Schmidt, T. The potential of Cassava biomass and applicable technologies for sustainable biogas production in South Africa. A review , *Renewable and Sustanable Energy Review*,vol.39 ,p1035-1052, 2014.

97. Pande,V.C, Kurothe, R.S, Rao, B.K, Kumar ,G, Paraniyal, A.K, Singh, A.K and Kumar, A. Economic Analysis of Bamboo Plantation in Three Major Ravine Systems of India, 2012.

98. Pereira, M.G., Sena, A.J, Freitas, M.A.V and da Silva, F.N. Evaluation of the impact of access to electricity: A comparative analysis of South Africa, China, India and Brazil, *Renewable and Sustainable Energy Reviews*, vol. 15, no. 3, pp. 1427-1441, 2011.

99. Pearce, P: Conference presentation slide titled "Why bamboo?" for Kasih coal dump in Indonesia, 2014. Unpupblished presentation.

100. Phimmachanh, S, Ying, Z and Beckline, M. Bamboo Resources Utilization: A Potential Source of income to support Rural Livelihoods. *Applied Ecology and Environmental Sciences*,Vol.5 no.6,176-183, 2015.

101. Piatti, L. Flüssige brennstoff aus bambus (liquid fuel from bamboo). Schweizer Archiv für Angewandte Wissenschaft und Technik 13, 370-376. No. CONF-8308231, *Center for Energy and Environment Research*, San Juan, 1983.

102. Poppens, R, Van Dam, J and Elbersen,W. Analysing the potential of bamboo feedstock for the biodiesel economy. Netherlands Agency programme for sustainable biomass, *Ministry of Economic Affairs*, 2013.

103.PwC.Forest,Paperand Packing:Forest industry:Application review of IAS41,Agricultue:the Fair Value of Standing Timber ,2003.

104.Rampedi, I.T. Indigenous plants in the Limpopo Province :potential for their commercial beverage production. Masters of Science thesis submitted to University of Pretoria, 2010.

105.Rao, A.N, Ramanatha, V and Williams J.T. Priority Species of bamboo and rattan, IPRG and INBAR,1998.

106. Ravallion, M., Chen, S. and Sangraula,P, "Dollar a Day Revisited," *World BankEconomic Review*, 23(2), 163-184,2009.

107.Rosenberg, M.T. 1999. Climate classification (available at http://clem.mscd.edu).

108. Sarfo, D. Bamboo as a source bioenergy feedstock in Ghana. Masters of Science thesis submitted to Ghana, 2008.

109. Scurlock, J.M.O, Dayton, D.C.and Hames. B. Bamboo: An overlooked biomass, *Biomass and Energy*, vol. 19, pp. 229-244, 2000.

110. Singh, A.N. and Singh, J.S. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region, *Forest Ecology and Management*, vol.119, pp. 195-207, 1999.

111. Singh, A.N, Raghubanshi, A.S and Singh, J.S. Impact of native tree plantations on mine spoil in a dry tropical environment, *Forest and Ecology Management*,vol. 187, pp.49-60, 2004.

112. South African Coal Roadmap (SACR). Overview of the South African Coal Value Chain. Available at: www.fossilfuel.co.za/initiatives/2012/SACoalRoadMap _FFF_Limpopo _Oct-12.pdf, 2014.

113. South African state of the Nationa Adress (SONA).Febraury 2014.

114. South African Weather Service Website . www.southafrica.info/travl/advice/climate.htm [accessed 2017].

115. Sutton, A. The potential of Bamboo in South Africa, Swellendam in Western Cape Province, 2013. [Unpublished presentation]info@afribam.com.

116. Taylor, F.G. Pollution control and mine site rehabilitation in surface coal mining, SCIRO environmental projects office, Osmond, Australia. 2004. Available at http://apec-egefe.fossil.energy.gov/TILF_VN2000/taylor%20paper.

117. Tewari, D.N. A monograph on bamboo . International book distribution, Dehra Dunn, 1992.

118. Teljwani, K.G., Gupta, S.K and H.N. Mathur. Impact of Human influences on the vegetation of the Western Himalaya. *Soil and Water Conservation Research* 1956-71. Indian Council of Agricultural Research, New Delhi, 1975.

119. The Biomass Corporation, 2008.http://www.biomasscorp.com/contact.htm. [Accessed 2016 June 17].

120. Truong, A.H. and Le ,T.M.A. Overview of Bamboo Biomass for Energy Production. University of Science and technologies of Hanoi, *Department of Renewable Energy*, 2014.

121. Tshiala, M.F, Olwich, J.M and Engelbrecht, F.A. Analysis of Temperaure trend of Limpopo Province, *South Africa, Journal of Geography and Geology*, 2011.

122. Van Renssen, C. Syferfontein mine, rehabilitation plan, Pretoria, South Africa, Van Renssen & Fertuih (Pty)Ltd , 2004.

123. Virta, R.L. Worldwide Asbestos Supply and Consumption trends from 1900 through 2003. *U.S. Geological Survey Circular* 1298 80p, 2003.

124. Volker R,Schaaf, H and Tachkov, P. Evaluation of Research and Technology Projects: A Status Quo Analysis of Technology-Intensive Companies. *International Journal of Technology intelligence and Planning, Vol* 5,2, 165-190, 2009.

125. Wang, D. and Shen, S.J. Bamboos of China. Timber Press, Portland, Oregon, 1987.

126. Watson, H.K. Potential to expand sustainable bioenergy from Sugar Cane in Southern Africa. *Energy Policy*, vol. 39, pp. 5746-5750, 2011.

127. Weyers-Liebenberg, D A multidisciplinary approach for the assessment of rehabilitation of asbestos mines in South Africa. University of North West, Masters of Science thesis Potchefstroom, South Africa, 2010.

128. White, D.G. Propagation of bamboo by branch cuttings, *Proceeding of American Society of Horticultural. Science*, vol. 50, pp.392-394, 1947.

129. World Energy Council. World Energy Trilemma Index. Benchmarking the sustainability of national energy systems, 2016 .www.world energy.org .

130. www. Africaneconomicoutlook.org.za, Theme Structural Transformation and Natural resources T2013 [Accessed 8 July2016].

APPENDICES

Appendix A: Financial Model

Table A1: Assumptions and data

	BAMBOO PLANTATION -	0				
	In Rands					14.71
1	**ASSUMPTIONS**					0.5
	Plantation Size	100	Ha			7.355
	Row Spacing (8m x 4m)	12.5	/Ha			
	Plant Spacing	25	/Ha			
	Plant Density	313	/Ha			
	Total Plants Required	**31 300**				
2	**CAPEX**					
	Description					
	Planting	**Per Plant**		**Per Ha**	**TOTAL**	
	Consulting	R	3.17	R 992.93	99 293	
	Manager	R	11.28	R 3 530.40	353 040	
	Plant Cost	R	51.00	R 15 963	1 596 300	
	Field Prep	R	17.65	R 5 525	552 508	
	Ripping	R	4.00	R 1 252	125 200	
	Hole Prep	R	4.00	R 1 252	125 200	
	Planting	R	4.00	R 1 252	125 200	
	Hydrogel	R	0.03	R 9	939	
	Equip & Tools					
	Tractors & Back Actor	R	39.48	R 12 356	1 235 640	
	Trailors & Implements	R	16.45	R 5 149	514 850	
	Water Tank	R	1.88	R 588	58 840	
	Vehicles	R	28.20	R 8 826	882 600	
	Quad Bikes	R	7.52	R 2 354	235 360	
	Loose tools & Equip	R	4.70	R 1 471	147 100	
	Equip Store	R	73.45	R 22 990	2 299 000	
	Reservoir/Dam	R	32.90	R 10 297	1 029 700	
	Irrigation & Pumps	R	47.00	R 14 710	1 471 000	
	Office	R	4.70	R 1 471	147 100	
	Office Equip	R	0.94	R 294	29 420	
	Plantation Maintenance					
	Irrigation	R	26.15	R 8 185	818 530	
	Weeding	R	12.00	R 3 756	375 600	
	Fert	R	2.82	R 884	88 401	
	TOTAL CAPEX	**R**	**393.32**	**R 123 108**	**12 310 820**	

CAPEX	**Per Plant**	**Per Ha**	**100 Ha**
Equipment	R 257.21	R 80 506	R 8 050 610
PLANTATION			
Plant Cost	R 51.00	R 15 963	R 1 596 300
Planting	R 44.13	R 13 814	R 1 381 379
Mintenance	R 40.98	R 12 825	R 1 282 531
	R 136.11	R 42 602	R 4 260 210
SUB TOTAL	**R 393.32**	**R 123 108**	**R 12 310 820**
OUT GROWER			
Plant Cost			
COMBINED	**R 393.32**	**R 123 108**	**R 12 310 820**

INCOME & EXP	**Price/Ton**	**Price/m³**	**Price/HA**	**Price/Stand**	**Price/Culm**
Income	R 1 765.20		R 82 876.14	R 264.78	R 52.96
Harvesting & Extraction					
Harvesting	R 176.52		R 8 287.61	R 26.48	R 5.30
Extraction	R 110.33		R 5 179.76	R 16.55	R 3.31
Cartage	R 7.36		R 345.32	R 1.10	R 0.22
	R 294.20		R 13 812.69	R 44.13	R 8.83
P&L	**R 1 471.00**	**R -**	**R 69 063.45**	**R 220.65**	**R 44.13**

Table A2 : Economic model based on the above assumptions

3 PRODUCTION			**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**TOTAL**
Culms/Stand	Harvested						3	4	5	5	5	5	5	5	37
Average Culm Weight	Kg	Dry					15	20	30	30	30	30	30	30	215
Yield / Stand	Kg	Dry					45	80	150	150	150	150	150	150	1 025
Yield / Ha	Tons	Dry					14	25	47	47	47	47	47	47	321
TOTAL HARVEST	**Tons**	**Dry**					**1 409**	**2 504**	**4 695**	**4 695**	**4 695**	**4 695**	**4 695**	**4 695**	**32 083**
4 INCOME & EXP															
INCOME (Farm Gate)	Price/Ton		**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**TOTAL**
Fuel Wood	R 1 765.20						2 486 284	4 420 061	8 287 614	8 287 614	8 287 614	8 287 614	8 287 614	8 287 614	**56 632 029**
Edible Shoots - 5 Tons/ha															
5 EXPENDITURE															
Overheads	Rate														
Land Rental	$0.00	Ha/p.a.													**-**
Consulting	R 33 098	pa		33 098	33 098	33 098	33 098	33 098	33 098	33 098	33 098	33 098	33 098	33 098	**364 073**
Manager	R 14 710	pm		176 520	176 520	176 520	176 520	176 520	176 520	176 520	176 520	176 520	176 520	176 520	**1 941 720**
Repairs and Maint	R 20 127	pm		241 518	241 518	241 518	241 518	241 518	241 518	241 518	241 518	241 518	241 518	241 518	**2 656 701**
Insurance	R 6 708.84	pm	80 506	80 506	80 506	80 506	80 506	80 506	80 506	80 506	80 506	80 506	80 506	80 506	**966 073**
Plantation Maintenance				1 282 531	464 001	88 401	88 401	88 401	88 401	88 401	88 401	88 401	88 401	88 401	**2 542 143**
Harvesting & Extraction	Rate/Ton														
Harvesting	R 176.52		-	-	-	-	248 628	442 006	828 761	828 761	828 761	828 761	828 761	828 761	**5 663 203**
Extraction	R 110.33		-	-	-	-	155 393	276 254	517 976	517 976	517 976	517 976	517 976	517 976	**3 539 502**
Cartage (Compacted)	R 7.36		-	-	-	-	10 360	18 417	34 532	34 532	34 532	34 532	34 532	34 532	**235 967**
TOTAL EXPENDITURE			**80 506**	**1 814 173**	**995 643**	**620 043**	**1 034 424**	**1 356 720**	**2 001 312**	**2 001 312**	**2 001 312**	**2 001 312**	**2 001 312**	**2 001 312**	**17 909 382**
P&L			**(80 506)**	**(1 814 173)**	**(995 643)**	**(620 043)**	**1 451 860**	**3 063 341**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	**38 722 647**
IRR	**14%**		**(12 391 326)**	**(1 814 173)**	**(995 643)**	**(620 043)**	**1 451 860**	**3 063 341**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	**6 286 302**	
Cumulative			**(80 506)**	**(1 894 679)**	**(2 890 322)**	**(3 510 365)**	**(2 058 505)**	**1 004 836**	**7 291 138**	**13 577 440**	**19 863 742**	**26 150 044**	**32 436 345**	**38 722 647**	

Appendix B: Detail calculations of the amount of energy to be produced and volume of *Dendrocalumus asper* needed based on technology provided by Afrimine and Greener Alternative solutions in Appendix C below

Assumption of biomass technology based on usage of *Dendrocalumus asper* as a biomass technology

- **Assumption – *Dendrocalumus asper* has energy content or calorific value of 17.87 MJ/kg which is 17870kj/Kg**
- **Technology used in the study is Combuster 50 kW provided by Afrimine Southern Africa (Pty)Ltd with overall efficiency of 85%**
- **The plant load factor for the Combuster is assumed to be 80%**
- **Electricity efficiency of the biomass combuster genset is 38%**
- **Therefore the overall energy conversion of the Combuster plant is (38% * 85%) = 32.3%**

HEAT CAPACITY

- **Heat rate of the Combuster Gasifier using standard energy conversion will therefore be**
  Note 1Kw = 3600 Kj/hour at 100% energy conversion efficiency to produce 1 unit electricity (1kWhr)
  So for Combuster with the overall conversion efficiency of 32.3 %, a heat input of (3600/32.3%) = 11145.51 Kj/kWhr is required to produce 1 unit of electricity.

BIOMASS QUANTITY

- **Biomass quantity required to generate 1 kWhr using Combuster as provided by Afrimine**
  Since *Dendrocalumus asper* has a heat value of 17.87 Mj/kg or 17870 Kj/Kg, therefore, to produce 1 kWhr electricity (11145.51/17870) =0. 623kg of biomass will be required.

NB! The above depends on the heat value of the biomass and therefore the higher the heat value the less biomass required

- **Biomass quantity required for Combuster with the output capacity of 50 kW (50/1000) = 0.05 MW**
  = (0.623 * 0.05 *1000) = 31.15 kg/hour, which is equivalent to (31.15/1000) =0. 0312 tons/hr of biomass is required to yield 1 kWhr electricity.
- **Based on the assumption above, the Combuster biomass plant will require (0.05 MW *80%*365*24) = 350.4 MW hrs /annum.**
  Fuel usage = (heat rate * unit sent out) / fuel CV
  = (1145.51 * 350.4)/17870
  = 218. 5 tons/annum, which is equivalent to fuel usage of (218.5/365) = 0.598 tons per day

Therefore, based on plantation production on 100 ha pilot plant above, the harvest in the first fifth year(5^{TH} year) is equivalent to 14tons/ha/annum and stabilizes in the 7^{th} year to 47tons/ha/annum.

Therefore a 50 kW capacity Combuster will require 0.598 tons of biomass per day to run efficiently ,hence you need large hactares to keep the Combuster running efficeintly

Appendix C:Quotes from OEM Supply Afrimine Southern Africa Pty.Ltd

311 Surrey Avenue
Ferndale
Johannesburg
South Africa
2194

Tel:+27 11 326 3500
Fax:+27 86 653 9748
Email: info@afriminesa.com
sales@afriminesa.com
www.afriminesa.com

Afrimine Southern Africa Pty Ltd

Company Reg: 2014/005604/07
VAT No: 4090247679
Import & Export Permit No: 20868206

PROFORMA INVOICE

Bill To: Godfrey Mothapo
Company: Mintek Ltd
Address: 200 Malibongwe Drive
Private Bag X3015
Randburg
Country: South Africa
Zip code: 2125
Tel: +27 11 709 4304

Date: 25 Jan 2017
Proforma No: 17-01-11
Reference: BIOMAS COMBUSTOR GASIFIER
Sales Rep: Martin Soul Chikwanda
Delivery Period: 4 to 8 Weeks
Payment Terms: 70% TT on Order 30% Balance on Commercial Invoice

Description	Quantity	Unit Price	Total Price
Turnkey Biomas Combustor Gasifier. 50KW, 1. Efficiency is 85%, 2. Biomass feed material per day needed to run the combustor efficiently; Sawdust and Shredded Wood: Will be about 60kg/hr,	1.00	1 956 520.00	1 956 520.00
Buket-type hoister or Sealed conveyor belt	1.00	45 000.00	45 000.00
Biomass gasifying furnace	1.00	109 000.00	109 000.00
Screw feeder unit	0.00	0.00	0.00
Dry-type cyclone	1.00	21 000.00	21 000.00
Wet-type rotating fire grate	1.00	15 950.00	15 950.00
Screw ash conveyer unit	1.00	19 500.00	19 500.00
Centrifugal force draft fan	1.00	13 870.00	13 870.00
Biomass tar filter	2.00	23 650.00	47 300.00
Gas pressurized blower	1.00	34 815.00	34 815.00
Surplus gas burner	1.00	103 500.00	103 500.00
Tube-type heat exchanger	2.00	43 350.00	86 700.00
Automatic control system	1.00	14 350.00	14 350.00
Biomass fuel hopper	1.00	25 900.00	25 900.00
(CUMMINS series, 400V 50HZ. Type: SDCA50G Biomass Generator Set, Includes the following: Alternator, Joining and Chassis, Cummins Biomass Engine, Exhaust gas pipes and Silencers, Control System, Start Device, Cooling system for Gensets, Standard spare parts ,tools, documents and accessories.	1.00	249 067.00	249 067.00
Shredder and Dryer system	1.00	450 345.00	450 345.00
Civil works, installation and commissioning cost	1.00	633 911.45	633 911.45

Computer generated

Packing: Export standard with wood package, The Quotation is CIF Burgersfort in Penge, Turnkey quotation. Equipment delivery time: Within 60 days after advance payment (Genset within 20 days) Warranty Period: Two Year, Efficiency of the gasification system: 76%, Electricity efficiency of the biomass genset: 38% Amount of Biomass feed material per day needed: About 2.4t/day based on 24 hours running per day	0.00	0.00	0.00

SUB TOTAL:		**ZAR 3 826 728.45**
Discount:	0.00%	ZAR 0.00
VAT:	14.00%	ZAR 535 741.98
TOTAL DUE :		**ZAR 4 362 470.43**

Account Details

Account Name	: Afrimine Southern Africa
Bank Name	: Standard Bank South Africa
Account Number	**: 023135891**
Branch Code	: 018005
Account Type	: Cheque
Swift Code	: SBZAZAJJXXX

Terms and Conditions:

Order Processing after Confirmation of funds in Afrimine SA Pty Ltd Accounts.

Answers to questions raised as per condition of the Area.

1. Climatic conditions of Burgersfort /Penge: The power plant have no strict climatic requirement, We need build insulation cover in the Combustor gasifier and genset at no extra cost.

2. Installation cost including labour: For the 50kw, approximately 15-20 days max, we will arrange two engineer to guide the installation, cost is R3460 Rand/day each person.

3. Efficiency of the combustor: Combustor efficiency is 85%

4. Amount of Biomass feed material per day needed to run the combustor efficiently:
Sawdust; Wood will be about 60kg/hr

5. Amount of Energy to be produced onn 50 kw: The energy will be about 43,000kcal/hr.

6. Average Maintenance cost per year: Less R50 000 - R65 000 Rand/year.

Appendix 1 KVT-E70SI Technical Data Sheet

Appendix 2 Perkins Gas specification limits

Appendix 3 Lanpac – XL High efficiency Tower packing for Biological scrubber

Appendix 4 Biogas SWG 100 analyser

We trust we have interpreted your requirements correctly and assure you of our full attention and best service at all times.

Yours faithfully

Barry Morgan
Director: Sales and Marketing

Robin Jones
Director: Projects

Appendix D : Currency Conversion Sheet

Currency Conversion Sheet from 1995 to 2016

Annual	ZAR /USD	ZAR /AUD	ZAR /CNY	ZAR /RUB	GBP /USD	JPY /USD	EUR /USD	DEM /USD	FRF /USD	AUD /USD	CAD /USD	USD /EUR
1995	3.64	2.69			0.63	93.18		1.42	4.94	1.35	1.37	
1996	4.30	3.37			0.64	108.79		1.50	5.11	1.28	1.36	
1997	4.61	3.42			0.61	121.04		1.73	5.84	1.35	1.38	
1998	5.53	3.47			0.60	130.75		1.76	5.90	1.59	1.48	
1999	6.11	3.95			0.62	113.69	0.94	1.84	6.16	1.55	1.49	1.07
2000	6.94	4.02			0.66	107.81	1.09	2.12	7.12	1.73	1.49	0.92
2001	8.61	4.45	1.04	0.29	0.69	121.51	1.12	2.19	7.33	1.93	1.55	0.90
2002	10.51	5.70	1.27	0.34	0.67	125.23	1.06	2.08	6.96	1.84	1.57	0.95
2003	7.55	4.90	0.91	0.25	0.61	115.87	0.88	1.73	5.81	1.54	1.40	1.13
2004	6.44	4.74	0.78	0.22	0.55	108.12	0.80	1.57	5.28	1.36	1.30	1.24
2005	6.37	4.85	0.78	0.23	0.55	110.17	0.80	1.55	5.28	1.31	1.21	1.24
2006	6.77	5.11	0.84	0.25	0.54	116.35	0.80	1.56	5.23	1.33	1.13	1.26
2007	7.05	5.91	0.87	0.28	0.50	117.80	0.73	1.43	4.79	1.20	1.07	1.37
2008	8.26	6.93	1.16	0.33	0.55	103.40	4.63	1.34	4.48	1.20	1.07	1.41
2009	8.41	6.58	1.23	0.26	0.64	93.60	0.72	1.41	4.72	1.28	1.14	1.39
2010	7.30	6.71	1.08	0.24	0.65	87.73	0.76	1.48	4.96	1.09	1.03	1.33
2011	7.25	7.48	1.12	0.25	0.62	79.71	0.72	1.41	4.72	0.97	0.99	1.39
2012	8.20	8.49	1.30	0.26	0.63	79.84	0.78	1.52	5.11	0.97	1.00	1.29
2013	9.64	9.30	1.57	0.30	0.64	97.63	0.75	1.47	4.94	1.04	1.03	1.33
2014	10.84	9.77	1.76	0.29	0.61	105.88	0.75	1.47	4.95	1.11	1.10	1.33
2015	12.78	9.58	2.03	0.21	0.65	121.06	0.90	1.76	5.91	1.33	1.28	1.11
2016	14.71	10.93	2.22	0.22	0.74	108.80	0.90	1.77	5.93	1.35	1.33	1.11

Appendix E: Assumptions for Bamboo Plantations costs in Penge Limpopo in South African currency

ASSUMPTIONS FOR BAMBOO PLANTATIONS COSTS IN PENGE LIMPOPO IN SOUTH AFRICAN CURRENCY									
A	GENERAL OVERVIEW								
1	Planting	Size							
		100	Ha						
2	Plant Prices	Plug							
	Plug	R 29.00							
	Bag	R 51.00							
3	Nurseries Hardening	Unit Size	Cost/m²	Capex	Cost/Plant				
	Incl irrigation	5 000	R 74	R 5 443	R 3.00				
B	NURSERY HARDENING								
1	Plants	Plantation		Ongoing Sales					
		Setup		Per Month	Per Annum				
	Plugs Purchased	31 250		10 000	120 000				
2	Growing Medium 1m³	R 956.00							
	Fert 25kg	R 736.00							
3	Salaries & Wages	Bag 2L	Bag 5L	QTY	Wage		Monthly		
	Supervisor	R 1.00	R 1.00	1	R 7 355.00	p.m	R 7 355.00		
	Plant Care - Perm	R 2.06	R 2.06	5	R 4 119.00	p.m	R 20 595.00		
	Bag Filling - Temp	R 0.71	R 0.89	10	R 177.00	p.d	R 1 770.00		
		R 3.77	R 2.94				R 29 720.00		
4	Bag	Bag Costs	Medium	Fert	Water & Elect				
	2L Bags 4lb or (Short)	R 0.03	R 1.91	R 0.15	R 0.03				
	5L Bags1gal or (Short)	R 1.00	R 4.78	R 0.15	R 0.03				
5	Structure Repl Cost	R 3.00							
		Plugs							
	Total 2L Bag Costs	R 37.88							
		Own Plugs							
	Mark-up 2L Bag Costs	R 13.12	74.28%						
	WHOLESALE PRICE	R 51.00							
D	PLANTATION								
1	Plantation								
	Plantation Size	100	Ha						
	Row Spacing (8m x 4m)	13	/Ha						
	Plant Spacing	25	/Ha						
	Plant Density	313	/Ha						
2	Equip & Tools	Rate/Plant	Per Ha		Full Price		Full Price		
	Tractors & Back Actc	R 79.08	R 24 712.80	2x4	R 500 140	4x4	R 735 500		
	Trailors & Implements	R 16.48	R 5 148.50	Trailors	R 220 650	nplements	R 294 200		
	Water Tank	R 1.88	R 588.40		R 58 840				
	Vehicles	R 28.24	R 8 826.00	4x4	R 514 850	2x4	R 367 750		
	Quad Bikes	R 7.53	R 2 353.60		R 235 360				
	Loose tools & Equip	R 4.71	R 1 471.00		R 147 100				
	Equip Store	R 73.57	R 22 990.00	1125m	R 1 471 000	Floor	R 828 000		
	Reservoir/Dam	R 32.95	R 10 297.00		R 1 029 700				
	Irrigation & Pumps	R 47.07	R 14 710.00		R 1 471 000				
	Office	R 4.71	R 1 471.00		R 147 100				
	Office Equip	R 0.94	R 294.20		R 29 420				
		R 297.16	R 92 862.50		R 5 825 160		R 2 225 450		
3	Planting	Rate/Plant	Per Ha						
	Plant Cost	R 51.00	R 15 937.50						
	Field Prep	R 15.00	R 4 687.50						
	Ripping	R 4.00	R 1 250.00						
	Hole Prep	R 4.00	R 1 250.00						
	Planting	R 4.00	R 1 250.00						
	Hydrogel	R 0.02	R 6.25						
		R 78.02	R 24 381.25						
4	Maintenance	Rate/Plant	Per Ha						
	Irrigation	R 26.15	R 8 172.22						
	Weeding	R 12.00	R 3 750.00						
	Fert	R 2.82	R 882.60						
		R 40.98	R 12 804.82						
6	Land Rental	Ha/p.a.	None the land to be used is public state land that has been contaminated and requires rehabilitation						
7	Water for Irrigation		Using the nearby olifants River depending on permits from Department of Water Affairs						