ST. CLEMENTS UNIVERSITY

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THIS IS A DISSERTATION SUBMITTED IN
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DEGREE IN RENEWABLE ENERGY TECHNOLOGY.

TOPIC:

BIOMASS RESOURCES ASSESSMENT AND UTILIZATION, ENVIRONMENTAL EFFECT OF BIOMASS REMOVAL AND ITS IMPACT ON GAMBIA ECONOMY.

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APPROVAL PAGE

This is to certify that this research project was carried out under my strict supervision and has been approved for submission to the Department in partial fulfillment of the requirements for the award of Doctor of Philosophy (PhD) in Renewable Energy Technology of St. Clements University.

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DECLARATION

I, Nya Joe Jacob do hereby declare that this work is entirely my own effort and where works of other persons have been used or referred to, the sources have been duly acknowledged.

Nya Joe Jacob.

Sign-----------------

FEB-2013.

DEDICATION.

This project is dedicated first and foremost to: Jesus, the Almighty God, who has made it possible for me to access the program and successfully saw me through it to the end;

To my parents of blessed memory Elder /Mr. Jacob Nya Udo and Madam Mary Jacob Nya
To my lovely wife, Mrs. Martha Joseph Nya.

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Abstract.

Biomass resources meet about 99.5% of the Gambia population’s energy needs, so they are vital to basic welfare and economic activity. Already, traditional biomass products like firewood and charcoal are the primary energy source used for domestic cooking and heating. However, other more efficient biomass technologies are available that could open opportunities for agriculture and rural development, and provide other socio-economic and environmental benefits.

The main objective of this research is to estimate the biomass resources currently and potentially available in the Gambia and evaluate their contribution for power generation and the production of transportation fuels. It intends to inform policy makers and industry developers of the biomass resource availability in Gambia, identify areas with high potential, and serve as a base for further, more detailed site-specific assessments.

A variety of biomass resources exist in the Gambia in large quantities and with opportunities for expansion. The study found that these resources are more than enough to cover the country’s annual electricity consumption of 297 GWh and oil consumption of 206 dam^3. While the contribution of food crop residues, animal manure, and municipal solid waste is small in comparison to other resources at a national level, they could play a valuable role in stand-alone electricity applications and be particularly effective for households in remote rural areas. The survey,data collection and analysis method is used in conducting this research with three working hypothesis tested at 0.05 significant level .Answers to the research problems envisaged in the course of this work are presented

The research considers potential biomass resources and the expansion of key existing resources, such as groundnut, rice, coconut and sugarcane, to evaluate their fuel and power production potential on available cropland. It is unrealistic to assume that all of this land would be used for cash crop cultivation. A portion of it may go under afforestation to maintain forest ecosystems and their unique biodiversity, or be used for food crops production and other agricultural activities, or be converted to urban land. Therefore, the research evaluates the fuel and power production potential of biomass resources under three scenarios: using 10%, 25%, and 50% of the available cropland for cash crop expansion.

The local production and use of biomass resources as substitute for fossil-based fuels offers many socio-economic and environmental benefits for Gambia including energy security, investment opportunities, job creation, rural development, decreased greenhouse gas (GHG) emissions, waste utilization, and erosion control. However, if not managed properly, biomass resource development could have negative impacts, particularly to the environment. These include deforestation, increased GHG emissions, loss of biodiversity, and soil erosion. The socio-economic and environmental implications briefly described in this dissertation should form the basis of a more detailed study on the impact of biomass resources development in order to guide appropriate national policies and measures.

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CHAPTER 1

1.0 GENERAL BACKGROUND

1:1 INTRODUCTION AND CONCEPTUAL FRAMEWORK.

There is an emerging consensus on the need to reverse the trend of global warming associated with climate change. The main goal is to quickly reduce emissions of greenhouse gases. The European Union [EU] is resolved to reduce member country greenhouse gas emission and is promoting the development of new energy policies as one important means to that end. These policies should lead both to the development of new and more secure energy sources and contribute to a reduction in the growing dependency of EU member states on imported fossil fuels.

To implement its renewable energy strategy, in March 2007 the EU formally committed to the 20-20-20 initiatives, which sets as target and objectives for 2020. These include [i] reducing greenhouse gas emissions by at least 20% of 1990 levels[30% if other developed countries commit to comparable cuts] [ii] increasing the share of renewable energy[wind, solar, biomass etc] consumption to 20% compared to 8.5% today, and [iii] cutting energy consumption by 20% of projected levels by improving energy efficiency. Renewable energy has gained greater importance over the years, and is today considered the solution to the energy future in Europe. Since 1990, the EU has been engaged in an ambitious and successful plan to become a world leader in renewable energy production and use. The strategic energy plans and policies of the EU, as well as those individual member states, established concrete targets for exploitation of indigenous renewable energy sources, and for bio-energy in particular. As a first step toward a strategy for renewable energy the commission adopted a Green Paper on 20 November 1996. The most ambitious strategic goals were defined in 1997 in a European Commission White Paper where the EU sets the target to increase the share of renewable up to 12% by 2010.The white paper also contains a comprehensive strategy and Action Plan setting out the means to reach this objective. After the order Green Paper [2000] on security of energy supply, diverse and concrete proposals were made.

One of these proposals, directive 2001/77/EC on electricity production from renewable sources, was adopted in 2001. Under this directive 22% of the electricity consumed in the EU by 2010 should be produced from the renewable energy sources.

Amongst renewable resources, paramount importance has been given to the bio energy because it has low negative environmental impact in terms of CO2 emission for the entire fuel cycle and zero CO2 emission from fossils fuels during operation. The European Commission White Paper recognized bio-energy as the most promising areas within the biomass sector for several reasons. First, because it would increase the amount of people working in the forestry sector. Second, because the combined use of heat and power [CHP] has the greatest potential per unit volume among all renewable energy sources.

They also issued the opinion that the contribution of biomass-derived energy to the primary energy mix should reach 10% by 2010. The European Commission Green Report [2000], also recognized that biomass is a versatile energy resource; with a wide spread availability through forest and agricultural residues that has so far not been fully exploited. Consistent with the Green report, emphasis is given to the electricity generation from biomass energy plants. The strongest incentives of the EU toward development of biomass energy were given in 2005 with the biomass Action Plan. In this plan, the EU stated that the increased use of renewable energy is essential for environmental and competitiveness reasons, and recognized that biomass has many advantages over conventional energy sources, as well as over some other renewable energies, in particular, relatively low costs, less dependence on short term weather changes, promotion of regional economic structures and provision of alternatives sources of income for farmers. This Action Plan established several measures to promote biomass in heating, electricity and transport, followed by crosscutting measures affecting biomass supply, financing and research.

According to this EU strategy, the goal of reaching 45% of national energy consumption in 2010 from renewable energy sources will be achieved in part from biomass energy production. Considering that wood-fuel demand will increase significantly and will be variable across regions, it will be necessary to apply rational resources exploitation actions associated with regional and local needs. For example, there may be significant competition in some areas due to the presence of pulp mills or other biomass consuming industries. In these cases special solutions and compromises will be needed, or it may not be feasible to construct a power plant in such a location. As stated in the 2005 EU report, the support of electricity from renewable energy sources, the future development of renewable energy sources projects in a specific area must taken into account spatial aspects of planning. This is especially fundamental for a research in the field of biomass. In this context the objectives of this research are to: [1] assess Gambia current forest biomass resources potential for commercial generation of electricity at national and regional levels. [2] Assess the spatial distribution of biomass availability, and [3] evaluate the suitability of existing and proposed wood- fired power plant location in Gambia.

Biomass is a non-intermittent Renewable Energy Sources that can provide energy to be used for heating and cooling, electricity and transport. Biomass fuels can easily be stored meeting both peak and baseline energy demands. Biomass can take different forms[solid, liquid or gaseous], and can directly replace coal, oil or natural gas, either fully or in blends of various percentages. Bio energy is CO2 neutral, as all carbon emitted by combustion has been taken up from atmosphere by plants beforehand. Bio energy consists of solid, liquid or gaseous fuels. Liquid fuels can be used directly in the existing road, railroad, and aviation transportation network stock, as well as in engine and turbine electrical power generators. Solid and gaseous fuels can be used for the production of electrical power from purpose-designed direct or indirect turbine-equipped power plants.

Biomass resources include primary, secondary and tertiary sources of biomass. Primary biomass provide economic growth through business earnings and employment, import substitution with direct and indirect effects on GDP and trade balance, security of energy supply and diversification. Other benefits include support of resources are produced directly by photosynthesis and are taken directly from the land. They include perennial short- rotation woody crops and herbaceous crops, the seeds of oil crops, and residues resulting from the harvesting of agricultural crops and forest trees[e.g. wheat straw, corn Stover, and the tops, limbs, and bark from trees]. Secondary biomass resources result from the processing of primary biomass resources either physically[e.g. the production of sawdust in mills,] ,chemically [e.g. black liquor from pulping processes], or biologically [e.g. manure production by animals].

Tertiary biomass resources are post- consumer residue streams including animals fats and greases, used vegetable oils, packaging waste, and construction and demolition debris. Bio energy contribute to all-important elements of national/regional development, economic growth through business earnings and employment, import substitution with direct and indirect effects on GDP and trade balance, security of energy supply and diversification.

Other benefits include support of traditional industries, rural diversification and the economic development of rural societies. Bio energy can also contribute to local and national energy security that may be required to established new industries. Additionally, biomass can be traded at local, national and international levels, providing flexibility to countries that have less biomass resources like Gambia. The EU depends heavily on imported energy for running its economy. For the transport sector there is hardly any diversification of energy sources: crude oil fuels more than 98% of the EU's transport sector. Biofuels have a major role to play in improving energy security and tackling climate change, which are the core objectives of the EU's biofuels policy.

Significant progress has been achieved on biomass production and conversion technology over the last decade resulting in the increase of competitive, reliable and efficient technologies. They are represented by dedicated large and small scale combustion, co-firing with coal, incineration of municipal solid waste, biogas generation via anaerobic digestion, district and individual household heating, and in certain geographical areas, liquid biofuels such as ethanol and biodiesel.

Due to the rapid growth in the population of the Gambia in recent years, demand for energy has far outstripped the ability of the State owned utility to supply the country. The gross energy consumption of the Gambia in 1998 was just over 308,000 tones of oil equivalent TOE which represents 0.28 TOE on a per capital Basis .The net energy demand for the Gambia in 1998 was estimated at 287,100 TOE, which is supplied from fire firewood (225,500 Toe), petroleum products (61,600 TOE and electricity (6,300 TOE). the two biggest energy consumer are households and the transport sector.

The Gambia's geographical location gives it plenty of sunlight hours. The country receives 2,500 hours of sunlight yearly and the daily solar energy potential is an average 2.5 KJ per square centimeter area (2.5KJ/cm2). The government is encouraging the use of alternative energy and the use of solar PV cells and associated equipment is on the rise be it for domestic, commercial or industrial use.

The use of alternative and renewable energy in the country is gaining recognition, especially the use of solar PV. This interest comprises both individuals and groups. However, the deterring factor in the widespread utilization of renewable is the initial cost of investment, which is beyond the reach of many Gambians. Most solar PV and wind installation are donor funded. The major energy resources in Gambia are firewood, electricity, petroleum import, Liquefied petroleum Gas [LPG]. The government has established Gambia Renewable Energy Center [GREC] and seeks to collaborate with interested companies, individuals, development charities ,entities for the development of renewable energy through R&D. The Gambia's annual consumption of LPG was estimated at 1,350 tons for the period, 1996 to 1999, while the estimate for year 2,000 was approximately 2,000 metric tons. The share of household consumption, in total imports, is estimated at 85%, the remaining 15% represent the consumption by the hotel industry.The provision of reliable electricity to the Gambia has become a priority for the Government and there are investment opportunities at all levels. Generating capital is substantially below demand, the distribution system,. While adequate for existing generating levels will need investment and particularly with the development of industry and tourism up-country, opportunities will arise there also.

The most commonly used energy resource in the Gambia is firewood. The burning of fuel-wood for cooking & other uses account for over 80% of total energy consumption in Gambia ranging from 228 thousand TOE to 375 thousand TOE from 1990 to 2004 fuel wood. According to the 2004 Energy Balance, in The Gambia, 485,000 tons of firewood is used annually to meet the energy needs of 90% of the population 60% of total fuel-wood used is consumed by the rural population for cooking.

Firewood has the largest share of both the national energy and the household energy balances. Its source is the forest and by virtue of this relation, its administration as produce of forest resource falls under the purview of the DOSFNRE as the line department of states responsible for forestry affairs. The Forestry Department is the technical organ responsible for technical advice as well as operational, administrative and managerial aspects of forestry in the Gambia.

The utilization of biomass is also on the rise though it tends to be limited to agricultural by - products such as wood shavings, peanut shells and straw. The forestry Act has provision for the regulation of the movement of forest produce. It requires producers and sellers of fuel-wood to be in possession of valid licenses issued by a competent regulatory authority, and only dead trees are allowed to be cut.

Programmes, projects and policy pronouncements implemented in the past by the Gambian Government includes: [1] A presidential Decree which banned the production of charcoal in 1980. The Government was concerned about the alarming rate of deforestation. [2] Introduction of improved cooking stoves in 1982 to reduce firewood consumption; [3] Promotion of butane gas as a substitute to firewood under CILSS/EDF Regional Butane Gas Programme in 1992; [4] Groundnut shell briquette production, 1982. This involved the manufacturing of briquettes in the Gambia from groundnut shell in bulk quantities to serve as an alternative to charcoal. ; [5] Establishment of the Gambia Renewable Energy Center [GREC] to serve as a research, development and promotion center for renewable energy technologies in 1985. This followed the oil shocks and droughts in the mid and late 1970s respectively; [6] Introduction of a biogas program.

This program attempted to introduce appropriate Renewable Energy technologies to the Gambian population to be able to extract gas from animal waste for their energy needs;[7] Plantations project started in 1950 by the Forestry Department to create more planted forests to serve as supplement to the already existing natural forests as a source of sustainable wood for fuel; furniture and construction building materials. [8] Shift from light fuel to heavy fuel oil in the mid 1980s as a means to make electricity cost affordable;

[9] Construction of a bulk storage facility and sea terminal for LPG at Bonto so as to be able to procure LPG at international market price to make it an affordable substitute to fuel-wood.

Wood -to-energy system can be produced anywhere from less than 1 megawatt [MW] to more than 100MW of power and can use wood exclusively or in combination with other fuels, such as coal or natural gas. This energy can be used to generate electricity; heat buildings with water, steam, or air [space heat]; produce steam for industrial processes; or power vehicles and machinery.

All of the processes involve breaking down the cellulose in wood to release the energy it contains. The simplest way to obtain energy from wood is through a process called 'direct combustion'. Energy from burning wood can produce power, electricity, or heat To produce power, wood can be burned in a boiler, a large combustion chamber, to heat water and generate steam.

Biomass power technologies convert renewable biomass fuels to heat and electricity using processes similar to those employed with fossil fuels. At present, the primary approach for generating electricity from biomass is combustion direct-firing. Combustion systems for electricity and heat production are similar to most fossil-fuel fired power plants. The biomass fuel is burned in a boiler to produce high-pressure steam. This steam is introduced into a steam turbine, where it flows over a series of turbine blades, causing the turbine to rotate. The turbine is connected to an electric generator. The steam flows and turns the turbine. The electric generator rotates, producing electricity. This is a widely available, commercial technology.

Combustion boilers are available in different designs, depending on application and biomass characteristics. The main options are to burn the biomass on a grate [fixed or moving], or to fluidize the biomass with air or some other medium to provide even and complete burning. Steam turbine designs also vary in terms of their application.

To maximize power production, condensing turbines are used to cool steam. Thousand of acres of forest and woodland in Gambia have been historically shaped by fire [Arno and Wakimoto 1988: Covington et al, 1994]. Whether induced by lighting or by humans, fire once was the primary means of recycling carbon and nutrients for many forests of all kinds. The Gambian settlement and the introduction of grazing, farming, forestry, and fire suppression greatly changed forest systems accustomed to fire regimes, and they underwent a long, slow buildup of woody biomass[Clark and Sampson 1995: Covington and Moore 1994: Everett et al. 1993]. In the absence of fire, undergrowth and small trees thrived. Such additional growth in the forest was welcomed for many years as a sign of management success [Langston 1995].

In recent years, however, the toll of fire suppression on the ecosystems has become evident. Plant communities too dense for the moisture and nutrient conditions of a particular site compete with each other for limited resources. When the competition becomes excessive during dry spells, major die backs occurs [USDA Forest Service 1996].Native insects and diseases are usually the agents of death, but the stress of competition is an underlying cause [Sampson et al.1994]. As mortality rates increase, so as do the flammable fuels. In the Gambian climate- characterized by dry summers and cold winters –biological decomposition is too slow to offset the fuel buildup [Harvey 1994].

As more living and dead fuels are present, both in larger landscape patches and in the vertical structure of the forest, any ignition in dry weather is likely to result in a major wildfire [Anderson and Brown 1988:Covington et al. 1997].Absent from any treatment to remove the fuel buildup, fires are inevitable [Sampson 1999]. The fuels have no other route for recycling, and they accumulate until they are removed or burned.

Where fuel loads are high and fuel structures continuous, the result is intense fire that often behaves so violently that suppression may be impossible. Such intense fires kill plant communities that were historically tolerant of milder fires, and their heat causes serious and often permanent soil damage [Borchers and Perry 1990:Cromack et al. 2000: Neuenschwander and Dether 1995: Sampson and DeCoster 1997]. Recent research suggests that areas of extreme heat and damage are becoming a larger percentage of the total affected area within a forest perimeter [USDA Forest Service 1996: Covington et al. 1997].

1 .2 GAMBIA FOREST INFORMATION AND DATA.

48.0% or about 480,000 ha of Gambia is forested, according to FAO. Of this 0.2% [1.000ha] is classified as primary forest. The most bio diverse and carbon-dense form of forest. Gambia had 1,000 ha of planted forest. Between 1990 and 2010, Gambia lost an average of 1,900 ha or 0.43% per year. In total, between 1990 and 2010, Gambia gained 8.6% of its forest cover, or around 38,000 ha. Gambia's forests contain 32 million metric tons of carbon in living forest biomass. Gambia has some 740 known species of amphibians, birds, mammals and reptiles according to figures from the World Conservation Monitoring Center. Of these ,0.3% are endemic, meaning they exist in no other country, and 0.8% are threatened. Gambia is home to at least 974 species of vascular plants.

A recent agricultural census held in the early part of the first decade reveals that 74% of farmers rear poultry. About 40% of farmers reported having cattle, compared to 38% for sheep and 58% for goats. The largest number of cattle is found in Basse [URD] and WRD. Major species of livestock in Gambia include cattle, sheep, goat, horse, donkeys, chickens and pigs. Poultry and small ruminant management activities have a low productivity rate and high mortality combined with yearly epidemics of Newcastle Disease and PPR [Peste des petits Ruminants]. Most of the cattle breeds are either zebus or tsetse resistant ndamas [a cross between the zebus & the West African Dwarf].

Vital Statistics of Livestock Units:

	Heads 2002	Growth Rate 1990-2000.
Cattle	327,000	1.1
Sheep & Goats	408,000	-1.8
Pigs	17,000	0.0
Poultry	591,000	0.7

Source: FAO 2005.

The livestock production system in Gambia contributes about 25% of annual agricultural GDP and 5% of total national GDP. From 1980 the economic contribution of the livestock sector to the Gambia's GDP has progressively increased from 4% to 5.5% with the monetary value realized by the sector increasing from D18.1 million in 1982 to D28.3 million in 1996.

Women play a major role in small ruminant production, representing 52% of the owners of sheep, 67% of the owners of goats and 43% of the owners of both sheep and goats. The average number of animals owned is quite low [about six head of sheep and goats each, out of which about three are breeding females]. Most of the breeding males are born in their respective flock and there are fewer breeding bucks than breeding rams.

Though most large game animals such as elephants have been hunted to extinction a long time ago, hippos can be found in the protected areas of the River Gambia National Park. The country has a diverse bird population which is unusual for its size. Over 560 species of birds have been recorded in this tiny West African State.

The mammals which are most often seen are baboons and monkeys. The species of monkey to be found are the western red colobus, pastas and the callithrix. There are also small antelopes such as the Maxwell's duiker, sitatung and bush bucks. Among the animals to be found in Gambia include aardvarks, hyena, Nile crocodiles, warthogs, bush pigs, monitor lizards, chameleons, geckos, puff adders, spitting cobras and green mambas. Bottle nose dolphins can be seen near the entrance to the river from the Atlantic Ocean.

The biodiversity of Gambian animals forms an important component of the country's biological assets from both economic and ecological points. Recent field studies of wildlife species report 117 species of mammals, 30 species of amphibians and 47 species of reptiles making a total of 194 species of wild animals in Gambia. However, these figures are mainly estimates and the true numbers might be higher if more thorough investigations are taken .Over five hundred and fifty species of birds have been recorded as of 2006. There are 6 wildlife protected Areas [WPAS], occupying a total land area of 3.5% or 37,772 of the total land area of the Gambia. Wetlands, which include marine, inlands waters, coastal ,seasonal fresh water ponds, mangroves and marsh areas are distributed countrywide and make up around 20% of the total land area Bao Bolong wetland reserve, the biggest protected areas and the first Ramsar site measures approximately 22,000ha.

The elephant, which used to be the country's national emblem, was last spotted and shot, back in 1913. The record trophy of the Giant Eland was shot in 1903.The buffon kob which used to be a common species in the Gambia has long since become extinct, together with other species like the backed duiker, lion, red river hog, korrigum and the topi. The west African Manatee and the Sitatunga are in danger of extinction.

However, like all other natural resources, certain fish species are threatened as a result of unsound human exploitation strategies ,such species include the lobster [palinurus spp] ,shark, [catfish arius heudeloti] and the white grouper [Epinephelus aetheus] to name but a few.

The Gambia is endowed with a rich avifauna estimated at 1 bird species every 21.0 km^2. It has no epidemics and only 2 species- the puff-back shrike [Dryoscopus gambensis] and spur winged Goose [plectropterus gambensis] bear its specific epithet.

The components of biodiversity are ecosystem ,species and generic diversity .From the point of view of the Gambia, biodiversity is not restricted to the wild fauna and flora and associated ecosystems but it embraces the rich of biological diversity found in our domestic species. This includes varieties of crops and domestic animal that have been bred and developed for thousands of years by farmers engaged in agriculture.

About 100 years ago water buck, kob and hartebeest occasionally in their season could be observed in Gambia. The smaller antelopes have not significantly decreased in numbers during this period probably due to the size of the human population.

There were always a few leopards living in Gambia, but they were rarely killed and hyenas certain locations became very bold and more troublesome, frequently killing cattle quite close to settlements .However , this apparent stable and healthy wild animal populations status was not a recipe for inaction. However, legal measures regulating the management and exploitation of wild animals were put in place Specifically, regulations were made under section 111 of ‘The wild animal, Bird & Fish Preservation ordinance’ 1901.

Mammals: Elephany, Giraffe Camelopardalis peratta, Hippopotamus Amphibious, congo Buffalo, Senegambian buffalo, Red River, west Africa Eland, west Africa Hartebeest, Korrigum Hartebeest Red flanked Duiker Maxwell's Duiker, Growned Duiker, Gambian Oribi, waterbuck, Buffoons kob Nagor Reedbok, Roan antelope, west African statunga, warthog.The bubal hartebeest, Roan Antelope ,and the water-buck are currently rare visitors from neighbouring Senegal. Unfortunately, whenever any of these animals cross into The Gambia, local hunters pursue them until they are either forced to move back or shot.

Out of the 117 species of animals known to have existed in the Gambia about 13 have become extinct, and a similar number is threatened with extinction. One rare bird which is much sought after by poachers for its skin is the Golden Cuckoo of Foni and other forest areas. The rising human population mixed with local food production practices, have led to the loss of a large part of the Gambia's forest cover as well as animals wildlife.

1 .3 THE GAMBIA: GENERAL BACKGROUND.

The Gambia is the smallest country (~11,000 km2) on the African continent, lying between latitude 13 and 14 degrees North, and 17 and 12 degrees West. It consists of a narrow strip of land some 400 km long and 30 km wide on both sides of The Gambia River. It is bordered on the north, east and south, by the Republic of Senegal and on the west, by the Atlantic Ocean.

1 .3.1 : Climate

The country has a Sahelian climate, characterised by a long dry season (November to May), and a short wet season (June to October). Rainfall ranges from 850 - 1,200 mm. Average temperatures range from 18 - 30oC during the dry season and 23 - 33oC during the wet season. The relative humidity is about 68% along the coast and 41% inland during the dry season and generally about 77% throughout the country during the wet season. The prevailing climatic pattern favours only a short agrarian production regime (on average three months) which is the main source of employment and food supply for 80% of the population. Low rainfall and its poor distribution in the past two decades resulted in drought conditions that have affected the vegetation cover and food production potential.

1 .3 .2 : Population

The population is now estimated at 1.33 million with a density of 130 persons/km2, placing it among the five most densely populated countries in Africa (UNDP, 2000). Population growth rate is estimated at 4.2%, of which, 2.8% is the natural increase while 1.4% is net immigration resulting from the influx of refugees from the war-torn countries in the sub-region. Almost 38% of the population is concentrated in the urban areas around Banjul, the capital city and environs, and the rest (62%) in the rural areas. About 60% of the population is less than 25 years old (about half of this number is under age 10). The implication of this for education, health, and other social sector public expenditures is daunting. More importantly is the implication for growth in the labour force for which the prospects of employment opportunities, and training, are bleak at the moment.

The relatively high population growth rate has been recognized as one of the constraints on development. The challenge lies in the fact that the populations of the country will double every 16 years with the possibility of neutralizing the benefits of economic growth and undermining the country's oft avowed goals of poverty reduction. The Gambia's social diversity is reflected in the different ethnic groups. The ethnic groups and local languages are Mandinka, Fula, Wolof, Jola, Serahule, Serere, Manjago and Aku (Creole). The majority of the population is Muslim (95%) and the rest are Christians. Despite the ethnic pluralism, there is harmony among the groups and intermarriage is common. There is no religious extremism and Muslims and Christians peacefully co-exist in the country.

1.3 .3 : Economic Policies and Trends.

The main features of The Gambia's economy are its small size, narrow economic base and heavy reliance on agriculture, with limited number of cash crops, mainly groundnuts. This makes the economy vulnerable to the vagaries of the climate and to price changes in the international markets for these products. In the late seventies and early eighties, the country experienced significant decline in economic growth. To address this situation, The Gambia embarked on a series of structural adjustment programmes aimed at restoring maco-economic balance and economic growth. Despite the gains recorded under these programmes, the structure of the economy remains weak and highly vulnerable to external shocks due mainly to the volatile nature of the major sources of revenue, namely re export trade, ground nut export and tourism.

1.3 .4 : Analysis of general country situation.

The Gambia is classified as one of the Least Developed Countries (LDC) in the world. The UNDP Human Development Report 2001 (UNDP, 2002) ranks The Gambia at 149 out of 161 countries, with a Human Development Index (HDI) of 0.396. The country has a GNP per capita of US$ 340 and a GDP per capita of US $1,100.

The GDP growth rate in the 1999-2000 period was an impressive 5.6%. About 64% of the total population live below the national poverty line, whereas 59.3% of the population live below US$ 1 per day, and 82.9% live below US$ 2 per day. The agricultural sector employs about 75 % of the labour force and contributes 21% of GDP with a growth rate of 2.7%.

The sector is characterized by low productivity stemming largely from poor rainfall and over reliance on outdated technology. Structural and cultural problems hamper the development of the sector thus frustrating efforts to achieve food security. Of those who are extremely poor, 91% work in agriculture. According to the Poverty Reduction Strategy Paper (PRSP), groundnut farmers in The Gambia are the poorest of the poor. As a percentage of GDP, the tourism industry grew by 3.7% as against 7.5% in 1998. The sector's contribution increased from 5.4% in 1998 to 5.7% in 1999. The telecommunication industry once again registered a significant growth of 8% and has emerged as the second most important industry in 1999 contributing 27.3% to the GDP. The electricity and water industries combined, grew moderately and registered a 2% growth, while the trade industry, the third most important in the economy contributed 21.1% to GDP. The total road network in The Gambia is 2,700 km long, of which 956 km are paved. The Gambia has 400 km of waterways, which include the Gambia River, the most navigable river in West Africa. Preliminary estimates indicate the balance of payments accounts recorded an overall surplus of 101.2 million Dalasi in 1999. This positive upturn is, however, largely attributed to an improvement in the capital account as a result of the increase in official loans and grants. The current account deficit including official transfers deteriorated, slightly, from 3% in 1998 to 3.8% in 1999 of GDP reflecting the influence of the merchandise trade deficit. During 1999 the total value of international trade was about 2.8 Billion Dalasi, a 5.4% increase over the 2.7 Billion Dalasi recorded for 1998. In 1999, total imports were valued at 2.6 Billion Dalasi, a 7.6% increase over 1998 while total domestic exports were valued at about 239 Million Dalasi. This resulted in a trade deficit of about 2.4 Billion Dalasi. The Gambia's total outstanding external public debt amounted to US$420.8 million in 1999. The World Bank and Debt Relief International have indicated that The Gambia is entitled to 18 to 20% of debt relief. Worthy of mention is the fact that no external arrears were accumulated. The IDA, IMF and ADB have indicated their commitment to giving debt relief to the Gambia. The Government of the Gambia is also engaging bilateral development partners in negotiations for more relief. It is envisaged that the Gambia will benefit about US$67 million in debt relief. The Gambia has been operating a liberal exchange rate system since 1986, with the Dalasi floating within the context of an inter-bank market.

There are no exchange controls or restrictions on current or capital accounts. In 1999, the Dalasi depreciated against all the currencies traded in the inter- bank market

1.3 .5 : Macro- economic policy and strategy.

The Gambia continues to implement free market policies and strategies as enshrined in Economic Recovery programme (ERP) and its successor programme, the Program for Sustained Development (PSD). These two development programmes were subsumed into a long-term development strategy, known as Vision 2020. A number of reforms have been and continue to be undertaken on both the fiscal and structural fronts. On the fiscal front, public finances will be strengthened through a further reduction in the budget deficit and an improvement in the structure of government revenue and expenditure, including a reduction of import tariffs. The structural measures will include encouraging private sector development, attracting foreign investment, facilitating economic diversification, deepening financial intermediation and upgrading the soundness of the banking system, resuming public enterprise reform, reforming the energy sector, strengthening the agricultural sector, strengthening the institutional capacity of the public administration, and implementing a comprehensive social agenda, especially in the education and health sectors. The Gambia's medium term strategy is embedded in the Policy Framework Paper, which has been replaced by the PRSP. An interim PRSP (SPA II) has been prepared and was launched in November 2000 and the final document was prepared and adopted in 2001. The PRSP defines and outlines a people-centered approach to the eradication of poverty. It sets out the poverty reduction strategy and the implementation modalities for Vision 2020.

1.3.6 : Human development and poverty.

According to the 2000 National Human Development Report (NHDR, 2000), HDI for The Gambia is 0.363 . The Life Expectancy Index (LEI) is 0.5, Educational Attainment Index (EAI) is 0.364 and the Real GDP Index (RGI) is 0.226. The figures reported in the global HDR are slightly different from those in the NHDR. The Global HDR (GHDR) reports an HDI of 0.396, an LEI of 0.37, an EAI of 0.37 and an RGI of 0.45. In terms of gender, the GHDR reports a gender-related development index of 0.388, while NHDR reports an index of 0.340. It must be noted that the GHDR figures have a two to three year time lag while those of the NHDR have a one-year lag.

Life expectancy at birth is still low at about 53 years overall, 52 years for men and 55 for women. Infant mortality was 73 per 1000 babies born in 2000, down from 159 per 1000 babies born in 1980.

The under-five mortality rate is about 110 per 1000 children. Prevalence of malnutrition declined to 30% in 2000. About 62% of total population, (53% in the rural and 80% in the urban areas) have access to safe water supply. Sanitation services are available for 37% of the total population (35% of the rural population and 41% of the urban population below for additional health indicators for The Gambia)). In the area of education, the overall illiteracy level stands at 63% and that for females at 78%. Industry and manufacturing sectors account for 12% and 11% of GDP, respectively. The services sector, which is dominated by the hotel industry and a vibrant informal sub sector, contributes about 67% of GDP (Figure 1.3), and is the main foreign exchange earner. The growth rate of the services sector is 4.3%. Rapid population growth and increasing urbanization have posed a threat to the environment and put pressure on limited natural resources, thus aggravating environmental problems such as soil degradation, loss of forest cover, loss of biodiversity and poor sanitation. Coastal erosion has become a serious problem. For example, in some areas along the Atlantic coastline, the beach has been retreating at a rate of 1-2 m per year for the past thirty years while severe coastal erosion has produced sandy cliffs two meters high in other areas. Soil salinity is another threat to the environment. Saltwater intrusion has destroyed many farmlands making many farming households poorer.

1.4: Sectoral Trends, Policies and Initiatives

1.4.1: Agriculture

The draft Agriculture policy objectives and strategies for agricultural development have been extended to the year 2020 and has been submitted to Cabinet for approval. Environmental degradation and depletion, increased pest and disease outbreaks, decreased use of vital inputs and low level of labour supply due to rapid rural to urban migration are major constraints besetting the agriculture sector. The focus of the new policy will be to increase farm productivity, diversify the farm household production and marketing mix and increase the share of household production to be marketed. The government is currently assisting farmers through the Federation of Agricultural Cooperatives.

Government will continue to support the Agro business Service Centre Association to introduce better seed varieties and to develop a commercially managed agricultural credit system. It has also taken cognizance of the fact that previous initiatives lacked the "ownership" element required to sustain them. As a result, Government is emphasizing grassroots-level empowerment of people and improvement of capacity at local levels.

1.4.2: Fisheries

The specific policy objectives of the fisheries sector as spelt out in the

Strategic Plan for the Management and Development of the Fisheries sector include the following:

(a) To effect a rational long-term utilisation of marine and inland fisheries resources;

(b) To use fish as a means of improving nutritional standards of the population;

(c) To develop and expand artisanal fisheries and increase Gambian participation, especially women in the fishing industry;

(d) To increase employment opportunities and net foreign exchange earnings in the sector;

(e) To improve the economic environment of fisheries with a view to enhancing the sector's contribution to the national economy;

(f) To develop aquaculture, and

(g) To regulate industrial fishing activities with a view to achieving sustainable output. Because fisheries resources are non-renewable, and subject to over exploitation, depletion and the influence of environmental factors, the under-pinning principle of the fisheries management system in The Gambia advocates for the enforcement of judicious and rational practices, consistent with the optimum exploitation and utilisation of fish resources.

1.4.3: Energy

The energy resource base of The Gambia comprises mainly of electricity, petroleum products, fuel wood, liquefied petroleum gas (LPG) and renewable energy. Electricity generation is almost exclusively produced using petroleum products. Because of the limited generation capacity, load shedding is frequent. The policy guidelines put in place to address the outage are increase efficiency of the utility sector, promotion of private sector participation in power generation and provision of affordable tariffs for the utility services by rehabilitating the transmission and distribution lines, installation of effective meters, together with vigorous billing system, use of 8 heavy fuel oil (HFO) generating sets instead of diesel oil sets and introduce demand side management. Other policy objectives in place include the encouragement of the use of renewable energy technologies and private sector participation in the supply and distribution of electricity.

1.4.4: Forests and forestry

Forests are estimated to cover about 48% of the land area of The Gambia and the forest cover is classified into four broad categories: Closed forest (26,800 ha), Open forest (62,600 ha) Tree and Shrub Savannah (347,000 ha) and Mangroves (68,000 ha) (Forster, 1983). The Forestry sector share of GDP is estimated at less than 1%. This does not, however, take into consideration the significant informal trade in timber and non-timber forest products (fuel wood, fencing posts, wood carvings, honey palm oil and kernel, and wild fruits) that occur locally in the rural areas and across the border. Forests provide more than 85% of the domestic energy need of the country in the form of wood fuel and about 17% of the domestic saw timber needs (EU/MNRE, 1992). The natural forest cover continues to be altered by forest fires, which remain the single most important cause of forest degradation. It is estimated that not less than 85% of the land area of The Gambia is burnt annually. Apart from wiping out regenerating trees and shrubs, forest fires also kill matured trees especially when the fires occur at the peak of the dry season when most of the vegetation is under severe water stress. The main objectives of the national forest policy are to:

1. Preserve, maintain and develop forest land resources covering at least 30% of totalland area;

2. Ensure that 75% of forest lands are managed and protected; and

3. Ensure that sufficient supply of forest produce needed by both urban and rural population is available. To achieve the above objectives, the forest policy will promote and encourage:

1. Popular use of affordable alternatives for energy in urban areas to bridge the gap

between the demand and what the forest can sustainably supply;

2. Community ownership and management of forest lands;

3. Multiple use of forest and forest lands;

4. Efforts in the development of new strategies for the prevention and the control of bush fire;

5. Active participation of private individuals and the private sector in the production of forest produce and its marketing;

6. Nationwide tree planting;

7. National awareness concerning conservation and rational utilization of forest resources; and

8. Urban forestry.

1.4.5: Water resources

The water policies of The Gambia are obsolete due to the increase demand and commensurate expanded mandate of the agencies responsible for the management of the water resources of the country. The Department of Water Resources (DWR), with the collaboration of donor partners (EC/EDF, UNDP, UNCDF and UNICEF), is working towards the updating of the policies, strategies and regulations of the water resources sector. There is undoubtedly a continuing need for the provision of basic water supply facilities in the rural areas to assure 100% access to potable water by the rural population. As a matter of policy, the modern concrete-lined well and the Mark II (improved type) hand pump have been adopted, as the standard well and hand pump in the country. The introduction of renewable (solar and wind) energy-powered pumps and complementary borehole construction as well as the installation of reticulation systems in towns and villages with large population is being vigorously pursued. The Private Hand-pump Maintenance Scheme and the training and use of Area Mechanics, initiated by the Gambia-German Hand-dug Wells (GITEC) Project is a policy that is presently being replicated across the country. Effective community participation includes community education with regard to water sanitation, well utilisation and maintenance, the appointment of a Village Well Committee and the financial contribution towards the cost of maintenance of the constructed well and hand pumps and water supply facilities in the villages. The introduction of economic incentives and user charges is being considered in the new policy and regulations. It is logical that the water resources of the nation should be controlled by law. This law should invest the DWR with statutory powers and responsibilities to control the abstraction of water by means of the issue of water licenses and other regulatory measures. The Water Resources Act should define the type of water rights to be adopted as regards surface water and groundwater. Basic and applied research is the key to future progress, and increased attention should be given to the overall coordination of research and exploration programmes in the water resources sector. It should be government policy to allocate funds to areas that promise the greatest advances in water management and technology use.

1.4.6: Biodiversity and wildlife

In The Gambia, the development of a strategy and policy concept for biological diversity started with the Banjul Declaration and the Wildlife Conservation Act of 1977. These documents, particularly the Banjul Declaration, provide the basis for the conservation and sustainable use of biological resources in The Gambia. Over the last two decades, the Government of The Gambia has taken various legal, policy and institutional measures to promote the conservation and sustainable use of the country's biodiversity. The most recent policy focuses on developing a comprehensive development policy framework, which includes institutional strengthening of public education to create greater awareness, conservation and research. The first ever comprehensive biodiversity/wildlife policy and a bio-safety and biotechnology framework for The Gambia have been developed and are currently under review for Cabinet approval, before enactment into a law by the National Assembly.

In the wildlife sector, the initial policy strategy was to set up a system of protected areas and a total of six national parks were established. The new policy objective is to increase national parks to 5% of total land area, and put an emphasis on community conservation and bio-diversity research to acquire baseline data. Various biodiversity-related sectoral laws support the above mentioned policy measures. These include the National Environmental Management Act (NEMA) of 1994, the Fisheries Act of 1995, the Fisheries Regulations of 1995, The Wildlife Conservation Act of 1977, the Wildlife Regulations of 1978, the Banjul Declaration of 1977, the Forest Act of 1997, the Forestry Regulations of 1998, the Plant Importation and Regulation Act of 1963 and the Prevention of Damage by Pests Act of 1962.

1.4.7: Waste management

The present policy direction on waste management is to relocate old solid waste dump sites to more appropriate sites and create land fills to better manage the ever increasing solid waste being generated in the country. Supporting policies and legislation include the NEMA, 1994; Public Health Act, 1990; Public Health Regulations, 1990; Banjul Market Slaughter House Regulations and Banjul and Kombo St. Mary's Slaughter House (Licensing and Management) Regulations Local Government Act (1963) CAP.33: 0130. The Local Government Authorities (LGA) (Dissolution and Appointments Decree 1994) appointed management committees with functions of regulating the disposal of refuse, the prevention, abatement and removal of nuisances, and generally for the oversight of health and sanitation. There are no set guidelines as to disposal methods in the legislation. The Waste Management policy objective is to preserve and improve the health and quality of life of all Gambians through sound environmental management. Problems addressed include poor sanitation, waste management and disposal. The policy targets the minimization of the waste management's impacts on human, fauna, flora and natural environment and minimization of landfill/dumpsite volume. The principle of the waste management policy is the prevention of waste production, waste utilization and recycling, and controlled disposal of waste, which cannot be utilized (after biological, thermal or chemical-physical treatment).

Significant progress has been achieved on biomass production and conversion technologies over the last decade resulting in the increase of competitive, reliable and efficient technologies. They are represented by dedicated large and small scale combustion, co-firing with coal, incineration of municipal solid waste, biogas generation via anaerobic digestion, district and individual household heating, and in certain geographical areas, liquid biofuels such as ethanol and biodiesel.

Biomass is the Renewable Heat source for small medium and large scale solutions. Pellets, chips and various by-products from agriculture and forestry deliver the feedstock for bioheat. Pellets in particular offer possibilities for high energy density and standard fuels to be used in automatic systems, offering convenience for the final users. The construction of new plants to produce pellets, the installation of millions of burners/boilers/stove and appropriate logistical solutions to serve the consumers would result in a significant growth of the pellet markets. Stoves and boilers operated with chips, wood pellets and wood logs have been optimized in recent years with respect to efficiency and emissions. However, more can be achieved in this area. In particular, further improvements regarding fuel handling, automatic control and maintenance requirements are necessary.

Rural areas present a significant market development potential for the application of those systems, hence the need for Gambia as a case study. There is a growing interest in the district heating plants which currently are run mainly by energy companies and sometimes by farmers cooperatives for small scale systems. The systems applied so far generally use forestry and wood processing residues but the application of the agro-residues will be an important issue in future.

Significant improvement in efficiencies can be achieved by installing systems that generate both useful power and heat [cogeneration plants have a typical overall annual efficiency of 80-90%]. Combined heat and power[CHP] is generally the most profitable choice for power production with biomass if heat ,as hot water or as process steam, is needed. The increased efficiencies reduce both fuel input and overall greenhouse gas emissions compared to separate systems for power and heat, and also realize improved economics for power generation where expensive natural gas and other fuels are displaced. The biogas-technology is becoming an important part of the biomass-to-energy chains. Biogas is produced from organic matter under anaerobic conditions in nature[swamps],in landfills or in anaerobic digestion facilities[fermenters].Various types of anaerobic micro-organisms produce biogas from liquid manure, silage, left over food, waste or other organic materials. Biogas can either be used to fuel a gas engine, which is coupled with a generator to produce electricity and heat or-after upgrading to pure methane-in natural gas grids or in filling stations as transportation fuels for gas vehicles. Typically biogas is used in a CHP unit to produce electricity and heat but also its role as transport fuels will increase in future. Biogas produced from energy crops such as corn, sweet sorghum or others yields high energy outputs per hectare, because the total plant can be used as raw material and 65-80% of the carbon contained in the raw material can be converted to biogas.

The use of biomass for power generation has increased over recent years mainly due to the implementation of a favourable European and national political framework. In the EU-25 electricity generation from biomass [solid biomass, biogas and biodegradable fraction of municipal solid waste] grew by 19% in 2004 and 23% in 2005.However, most biomass power plants operating today are characterized by low boiler and thermal plant efficiencies and such plants are still costly to build. The main challenge therefore is to develop more efficient lower-cost systems. Advanced biomass-based systems for power generation require fuel upgrading, combustion and cycle improvement and better fuel-gas treatment. Future technologies have to provide superior environmental protection at lower cost by combining sophisticated biomass preparation, combustion and conversion processes with post-combustion cleanup. Such systems include fluidized bed combustion, biomass –integrated gasification, and biomass externally fired gas turbines.

Biomass resources cover various forms, such as products, from forestry and agriculture, by-products from downstream agro and wood based industries, as well as municipal and industrial waste streams [the biodegradable fraction].Dedicated woody or herbaceous energy crops can be grown, and transformed into various forms of energy. Improved agricultural and forestry practices can result in higher yields per hectare and per unit of input. New methods in erosion control, fertilization, and pre-processing can result in improved life cycle performance, sustainable practices, and enhanced feedstock production.

To optimize the potential of biomass resources in the Gambia, efficient technologies need to be developed for household cooking, crop drying, and power co-generation. An overview is presented to describe the role of biomass in creating a more sustainable energy economy. Biomass could be used in household cooking and in power generation for agricultural processing. The potential to dedicate land specifically to biomass production is limited by the availability of surplus land. With current residue production levels, biomass could supply approximately 160 MW to the nation (ESMAP 1993), representing 1% of the total supply by 2004. However, the comparative advantage of using biomass in this market is restricted, as the material appears to have higher value for other markets such as fuelwood for cooking, activated charcoal, or building materials. In the household-cooking sector, wood use is on the decline because prices are rising and deforestation is severe. In the Gambia, households are using more convenient fuels such as LPG and kerosene, or they are switching to crop residues for cooking. There is a need to develop efficient, clean burning biofuel cooking-systems and dedicated biomass energy crops as fuel sources to prevent additional consumption of imported LPG and kerosene.

An improved rice hull cooker, the LT-2000 Multi-Fuel Stove, is able to utilize various agricultural residues (rice hulls, maize cobs, coconut husks). The introduction of stoves to the Gambia could replace the equivalent of fuel wood . The stove has the lowest annualized cooking cost of all cooking systems using purchased fuel. The second opportunity identified was a pellet fuel stove for people residing in cities and towns near agricultural areas. Using, napier grass, or wood residues as a biofuel, these stoves could have a projected annual fuel cost 30% below that of LPG while providing the same user convenience. Advances in pelleting technologies will enhance the potential for widespread introduction of pellet fuel cook stoves in the future. Pellet furnaces can also be used for crop drying and commercial applications such as baking and food processing. Biomass energy could also aid in modernizing the agricultural economy.

Coconut, groundnuts and rice processing demand large amounts of energy and produce substantial amounts of energy rich by-products. Utiliziling these residues could make processing industries largely energy self-reliant.

Biomass can play a major role in helping reduce oil imports if efficient biomass energy conversion technologies are developed. The most appropriate role for biomass appears to be as a low-grade heat source. Improved biomass cookers and new cooking fuels could have a dramatic impact. Health improvements, reduced ecological impact on the landscape and biosphere, and an effective response to the economic crisis within the country by creating employment and displacing imported goods and fuels, can be facilitated by the increased utilization of biofuels.

1 .5 .0 General Overview of Biomass Energy Utilization in the Gambia

Biomass largely provided the energy requirements of the Gambia when tropical forests covered the islands and the population was modest. At the beginning of the 21st century, biomass energy still plays a vital role in the country's energy supply. Nearly 30% of the energy for the 1.5 million people living in the Gambia comes from biomass. Most is used for household cooking by the rural poor. More than half of Gambia households have an income level under 500 dalasis per month (Department of Energy 1995) and will probably have little choice but to continue using biomass fuels in the future. There is an urgent need to assess and develop new options for modernizing the role of biomass in the Gambia energy economy. With rising fossil fuel prices, demand for both forest and agricultural biomass resources will increase. To lessen the environmental impact from overexploitation of these resources sustainable utilization strategies need to be explored. The Gambia is among the most vulnerable country with regard to climatic instability and experiences some of the largest crop losses due to violent climatic events. As a result, the country has strong self-interest in advancing GHG-friendly technologies such as biofuels. The Gambia could become a model for other developing country to follow, with a broad portfolio of renewable energy sources.

Biomass currently represents approximately 29% of primary energy consumption. Wood supplies an estimated 60% of this energy, with agricultural residues from rice, and groundnuts industries supplying the remainder. Biomass energy contributes approximately twice as much energy as other indigenous energy supplies in the Gambia, including coal, hydro, and geothermal energy. Biomass energy plays an important role in reducing oil imports, particularly since oil prices have risen. Approximately 80% of the coal and 100% of the oil used in the Gambia is imported.

Oil intensifies the detrimental impacts on the trade balance of the Gambia as 50 million barrels of fossil fuels are imported each year, representing more than 3.5 million dollars. The use of imported coal for power generation is also increasing, and currently represents about 10% of imported oil energy.

In 1999, diesel and fuel oil represented 34% and 28% of the major petroleum imports, respectively. Among petroleum products, demand for LPG is expected to increase the fastest, with 10% growth per annum expected until 2008 (Gambian Energy Plan 1999). Demand will be driven primarily by increased use of LPG for household cooking. Growth of kerosene use is expected to be slower, as it will be replaced by electricity in lighting applications and LPG in cooking. Large natural gas is expected to displace oil for power generation in the future. Potential exists to develop a larger, renewable energy base for power generation in the future. In particular, hydro and geothermal energy sources show promise for future expansion. Hydropower production (including mini- and micro-production) has a target of 402 MW for 2008 (Gambia Energy Plan 1999), with a total power production potential of approximately 500 MW for geothermal energy.

Relative to hydro, geothermal, wind, and solar energy sources, the potential impact to the electrical power supply from biomass power production in the Gambia is limited. With current crop residue production levels, biomass could supply approximately 160 MW to the power grid (ESMAP, 1993), representing 1% of the energy supply by 2004. Furthermore, the advantage of using biomass in this market is restricted, as the material appears to have higher value for other markets such as firewood, activated charcoal, or building materials. Approximately ¾ of the biomass energy currently used in the Gambia is employed in the household/residential sector, with the remaining 25% dedicated to the industrial sector. Overall, biomass appears to have two main uses: (1) to provide low grade heat for household cooking and water heating, and (2) to provide process energy for agricultural industries that generate unused crop residues. For example, rice and groundnut trash can be used to generate internal electricity.

The tremendous energy requirement for low-grade heat applications in rural areas where biomass is readily available is an ideal opportunity for bio fuels. Biomass meets rural energy requirements in terms of energy quality and scale, and the use of biomass in household cooking and agricultural industries will likely continue. However, with the rising population of the Gambia outpacing the country's rate of food production, there is not enough surplus land to develop dedicated biomass energy crops for power generation. An ongoing agrarian reform program is being implemented to redistribute large farmlands to impoverished peasants. The contribution of biomass to energy generation must be balanced with other development priorities

Strategies that optimize the biomass for energy without sacrificing food security or long-term productive capacity of the soil should be favored.

There has long been interest in power generation from biomass in the Gambia. In the 1970's, a program to install Dendrothermal plants to be fired with wood was implemented. Initially, the government intended to supply the wood from captive plantations managed by cooperatives of small tree farmers (Durst 1986). However, these plantations were greatly affected by high financial costs and government cuts on funding and financial aid that were a result of the economic crisis of the mid-eighties (Durst 1986). The operation of the dendrothermal power plants thus suffered from both low wood production levels and political and economical instability. Since that time, much of the focus on power generation has involved developing co-generation opportunities within the rice, and groundnuts processing industries rather than stand alone plants which have no on site biomass supply. These COGEN plants have a demand for crop processing that can utilize low-grade waste heat produced during power generation. A number of detailed reports were produced which overviewed the COGEN opportunity, most of which were performed within the rice and groundnuts industries (ESMAP, 1993). The analyses indicated that the best opportunities lie with internal power generation requirements within the industry with some surplus. In the case of the groundnuts industry, the main opportunity is the need for a sustainable biomass fuel supply during the off-milling season to justify the investment in power co-generation at the facility.

A number of studies have been performed to assess the utilization of rice hulls for power generation in the Gambia. The potential aggregate rice-hull fired capacity is estimated to be no more than 40MW (ESMAP, 1993). Compared to groundnuts burning, the corrosive nature of rice hulls increases the risk associated with their use as a boiler fuel. There is need for skilled labor to operate the systems. The technology is being successfully implemented in countries such as India.

According to the ESMAP study (1993), the sale of rice hull ash would increase the financial return of rice hull power generation, improving the internal rate of return by 11%-24%. To be financially viable, projects need to install a minimum of 350KW. Presently, only systems above 500KW are assumed to generate sufficient power to produce surplus electricity for the grid. Most of the power from the smaller units could be used to displace diesel-generated electricity for internal plant use. The ESMAP study (1993) also indicated that because mills are normally in areas with low power demand, a sufficient load factor (85%) could be difficult to attain. However, a sufficient supply of rice hulls or other biomass for a plant of this size could be problematic.

First, the over-loaded Gambia road network creates major logistical problems for transporting long distances.

There could also be increasing demand for biomass resources such as rice hulls for cooking. If fossil fuel prices continue to climb, biomass costs could rise as a result of higher transport costs and competition from other users of the material. The increasing availability of cooking stoves and crop dryers capable of using rice hulls could make this resource disappear quickly. The disappearance of surplus peanuts husks,(as a replacement for bunker fuel) indicates that biomass power generation could rapidly run into supply problems. Additional challenges include the seasonal availability of rice hull, creating storage problems, and increasing climatic instability. The water demanding rice crop is particularly vulnerable to droughts, and the rice hull supply could be severely restricted during these periods. The past failure of Dendrothermal plants indicates that supply problems rather than technological difficulties may be the greatest challenge for power generation from biomass. Based on current understanding of power generation opportunities from rice hulls, one promising approach is the communal rice hull power plant (1-3 MW capacity) where rice hulls are provided by nearby plants. Waste heat produced could be used for crop drying and residual ash could be sold.

The advantage stemmed from:

- in-plant rice hull availability
- ratio of communal power generation capacity vs. communal peak power load
- distance of participating rice mills from the pilot plant site
- access to other paddy supply
- manageability of rice mill owners When surveyed, rice mill owners in Gambia were receptive to the idea of accessing a more reliable and cheaper source of power. Frequent power outages in the Gambia creates power shortages, which have forced some rice mills to stop operations because of the prohibitive cost of running backup diesel engines.

Overall the experience with biomass power generation has been one of limited success, with the exception of internal use within the groundnuts industry. Future developments are likely to be restricted to increasing bio-power use in agricultural processing facilities to reduce their dependency on the power grid.

To optimize biomass fuels for household cooking, it is essential that the social and economics aspects are understood.

The types of foods being cooked, where cooking occurs (rural and urban areas), family economics, and health risks all play a significant role in fuel use. It is also important to consider available fuels, how these fuels are procured, recent trends in fuel use, factors people consider when choosing cooking fuels, and the availability of biofuel sources and cooking systems that can provide more economical and environmentally friendly energy for household cooking.

The traditional Gambia diet revolves around rice, fish, and vegetables. The preferred staple food is rice, but maize is also widely eaten in the upland regions. . Meals are generally prepared in a large aluminum pot over a biomass stove. Rice or maize is cooked first followed by vegetables which cook more quickly. Fish and meat are commonly cooked in the same pot as vegetables. Dried and fresh fish are pan-fried in oil, and fresh fish and chicken are also grilled over charcoal. Roasting maize over biomass stoves is also popular. Baking is uncommon at the household level, though Gambian enjoy purchased baked snacks. Coffee is also very popular, and water is boiled several times per day or stored in thermoses to make instant coffee. . School starts early in the Gambia (often about 8:20 am) and time is valuable in the morning, particularly in rural areas where transportation time is lengthy. The weather also has an important influence on cooking because gathering dry fuel wood is difficult in the rainy season. Families often supplement wood cooking with charcoal and/or use more kerosene as fire starter. Open wood fires are generally made underneath pots which are supported by steel rails . Relatively simple firewood and charcoal clay stoves are also common. Exposure to smoke from fuel wood stoves is high for women and children.

The potential environmental outcomes of woody biomass removal are complex and inter-related. Effects may be positive, negative or a mix of both. The Research Synthesis that follows has sections on plant, wildlife, soil, water and air quality effects. Very few studies identified in this research address the effects of forest biomass removal specifically. Most information came from related research on the effects of thinning and fuel reduction treatments.

In general, opening up dense stands over time increases under story plant biomass and biodiversity, and habitat diversity for wildlife. Conifers may re-establish but newly open habitats may also be colonized by other native plants, or by invasive exotics. Thinning densely stocked ponderosa pine and Douglas-fir stands generally improves the vigor of remaining trees by reducing competition for water and soil nutrients. Increased tree vigor can reduce susceptibility to insect attack. Thinning creates new germination sites and canopy openings that may increase light, water, nutrient availability and soil temperatures.

However removing a portion of standing trees can also increase the susceptibility of residual trees to wind throw and alter fire behavior by facilitating increased wind speeds through the forest. Additionally, residual trees may be damaged during biomass removal.

The Gambia's biomass resource is large and diverse. The full extent to which it can be managed for the production of energy and products remains speculative, however, due to uncertainties concerning the gross magnitude of the resource, the quantity that can be used on a sustainable basis, and the costs of producing, acquiring, and converting the large number of biomass feedstock available and those that will emerge in the future. The principal sources of biomass in Gambia are agriculture, forestry, and municipal wastes. All three of these sources provide biomass as residues of other operations and activities. In addition to the primary commodities already produced, agriculture and forestry can also expand or shift into production of biomass commodities for new energy and biomasses product development. The total or gross estimated countrywide resource as of 2003 amounts to 86 million dry tons7, although the uncertainty of this estimate may be 10% or more. Biomass is a distributed resource with development opportunities across the entire country.

The most concentrated sources are those associated with municipal waste collection and disposal, confined animal feeding operations (CAFO), food and agricultural processing, and forest products manufacturing. Not all of the biomass produced in the Gambia can or should be used for industrial purposes. For example, not all agricultural crop or forest management residue should be harvested where it is needed to maintain soil fertility and tilth or for erosion control. Similarly, terrain limitations, environmental and ecosystem requirements, collection inefficiencies, and a number of other technical and social constraints limit the amount of biomass that can actually be used. For these reasons, amounts that can technically be supplied to utilization activities are substantially less than gross production.. Additional economic constraints further limit development. The latter are site specific and require detailed analyses for any proposed project. The combination of economies of scale for capital equipment, increasing feedstock acquisition cost as production capacity increases, and other effects often leads to an optimal facility size. Development of biomass power systems will for this reason occur over a wide capacity range from a few kilowatts to multi-megawatt units depending on location, resource availability, transportation and other infrastructure, conversion process, regulatory conditions, product, and market. Biofuels and bioproducts manufacturing will likewise develop over a wide range of sizes and capacity.

Conifer root diseases can cause significant tree mortality but are also natural and necessary decomposers in forest ecosystems. Root disease effects may be considered beneficial or detrimental depending on social values, landowner goals and management objectives for the stand. Fuel treatments can influence root disease in complex ways that should be considered at the stand level. It is beneficial to know where root diseases occur in a stand before removing biomass, and to avoid wounding trees during harvesting. Wildfire is a key ecological process, but effects of uncharacteristically severe fires may be negative and substantial. Topography and weather may play greater roles than fuels in governing fire behavior, but woody biomass fuel is the only aspect of the fire environment- fuels, topography, weather- that resource managers can alter. While thinning can reduce crown fire potential and mitigate crown fire severity, it can also increase surface wind speeds. Thinning allows for more precise and controlled fuel treatments than prescribed fire, but should not be considered the ecological equivalent of fire. Thinning ladder fuels without prescribed burning or removal of this biomass can increase surface fuels, crown scorch and tree mortality in subsequent wildfires. Coarse woody debris (large down logs and standing snags) is essential for many wildlife species, but also contributes to fuel loadings and is often consumed during wild fires.

Active management of stands of small diameter trees established as a result of past human actions can address wildlife habitat fragmentation and promote habitat maintenance and restoration. However, there are tremendous knowledge gaps in how different animal species will respond. Fire-dependent species, species preferring open habitats, and species associated with early successional vegetation or that consume seeds and fruit usually benefit from fuel treatments. On the contrary, species that prefer closed-canopy forests or dense under stories, and species that are closely associated with large snags or down logs that may be removed by fuel treatments, will likely be negatively affected from both fuel treatments and fire. Some habitat loss, such as under story vegetation, may persist for only a few months or years, but lost large snags and down wood may take decades to recover and are thus important to conserve. Biomass removal prescriptions that retain untreated refugia stands and create a mosaic of different forest structures across the landscape will likely support greater wildlife species diversity than large, homogeneous stands given the same treatment. Individual species responses may also vary over time. A small mammal species that needs shrub cover to avoid predators may decline following treatment, but then later exceed pretreatment levels when shrubs recover, and food resources increase from greater light, plant growth and seed production that result from opening up the forest canopy. While relatively rare, most forest carnivores have fairly large ranges so few species will be significantly affected by stand-level fuels projects.

However, some could be affected by any loss of denning habitat and changes in prey populations due to cumulative effects of past management, past disturbances and larger scale projects. Both marten and fisher are sensitive to loss in canopy cover and are strongly associated with coarse woody debris cover. Ungulates such as deer and elk use dense thickets of shrubs and trees as thermal cover, to hide from predators, for daybeds and for fawning, while also utilizing open areas for foraging. Thinning generally increases forage quantity and quality for ungulates, but retaining patches of dense cover is important. A mosaic of thinned and unhinged areas probably benefits deer and elk more than thinning uniformly across broad areas. Elk may be more likely than mule deer to benefit from thinning treatments.

Small mammal species vary in habitat preference and thus in response to biomass removal. Shrubs and coarse woody debris provide important cover from predators. Loss of these habitat elements may negatively impact some small mammal species. Species that prefer open habitats can benefit from food provided by fruit-producing shrubs, grasses and forbs that may establish after fuel treatments. Small mammals seem to decolonize disturbed areas quickly, although diversity and species dominance differ as succession progresses. Thinning can reduce truffle production and in turn populations of small mammals such as chipmunks and flying squirrels that feed on these fungi. Little data exists on the direct effects of fuel treatments on bats, but several species roost under the bark of tall, large-diameter trees or in cavities of large snags. As long as large snags and trees are protected, thinning may have minimal or even positive effects on bat populations depending on initial site conditions and land use history. Loss of these habitat features may be detrimental to bat populations. In Gambia dry conifer forests, bird community composition depends largely on the diversity of habitats available.

Reported effects of fuel treatments on birds are somewhat inconsistent. Stand scale effects may differ from those at the landscape or regional scale. Fuel treatments are likely to reduce nesting habitat for some species. Treatments during the nesting season may result in high mortality of nestlings. Bird species that prefer early successional and open forests are likely to increase in abundance after fuel reduction. Opening densely stocked, second growth stands has been shown to increase bird species diversity, especially in sub-Sahara African country like the Gambia. Thinning forest under stories may benefit hawks, owls, and eagles that prey on small mammals. But treatments that reduce density of pole-sized to mature trees are likely to negatively impact accipiter hawks, which are closely associated with very dense stands. Removal of trees with dwarf mistletoe brooms will likely impact raptors that nest in the brooms including the great gray owl, long-eared owl, great horned owl, northern spotted owl, northern goshawk, Cooper’s hawk, and red-tailed hawk.

Spotted owl management guidelines specify little active management in defined habitat areas. To the degree that they reduce the risk of stand-replacing fires in these areas, restoration treatments outside of them should benefit spotted owls over time. Variable density thinning in mixed conifer forests may accelerate development of northern spotted owl habitat and dense prey populations especially when snags, cavity trees and large downed wood are conserved. Thinning may reduce northern spotted owl habitat quality locally, but this should be weighed against the risk of stand replacing fires and loss of habitat over large areas. If fuel treatments remove snags, loss of nesting habitat for primary cavity nesting birds (e.g. woodpeckers) and secondary cavity-nesters (e.g. western bluebirds) might be expected for many years. Several studies showed that thinning or thinning and burning treatments result in reduced populations of cavity nesters due to loss of dead trees used for nesting and roosting. Other studies showed that thinning densely stocked conifers in landscapes dominated by younger stands enhances habitat for several species of songbirds. A variety of thinning intensities and patterns, from no thinning to very widely spaced residual trees, can maximize bird diversity at the landscape scale.

Thinning that result in vigorous under story shrub growth may also promote greater bird abundance and diversity. Few lizard and snake species occupy Gambia closed canopy coniferous forests, although reptiles do inhabit specific forest patches, such as wetlands, meadows, and rock outcroppings that provide shelter, microclimates, and prey. Leaving snags and down wood on site should benefit the many lizard species that prefer these habitat elements to live trees. Little is known about the effects of thinning on reptiles, but most species would probably benefit from reduction in shrubs, ground vegetation, and litter cover as long as snags and down wood are left on site. Amphibians' response to reduced canopy cover from either fuel treatments or fire will likely be negative due to warmer, drier conditions created in under story vegetation, down wood, litter and soil. Most salamanders need moist soils or decomposing wood to maintain water balance, so dry conditions usually result in suppressed populations. Frogs and toads may be less affected by fuel treatments because they tend to travel at night and during rain events, they are more mobile than salamanders, and they are closely associated with wetlands. Treatments that increase surface runoff and contribute fine sediment to streams may reduce egg and tadpole survivorship of some stream-breeding amphibians that lay eggs and rear tadpoles under rocks or in spaces in stream cobbles. Fuel treatment effects on terrestrial invertebrates in Gambia dry coniferous forests (insects, spiders, mites, scorpions, centipedes, millipedes, isopods, worms, snails and slugs) are probably as diverse as the group itself. Invertebrates comprise over half of the animal diversity in forests, occupy all forested habitats and have varied ecological roles including decomposers, predators herbivores and pollinators.

Some invertebrates can explode in population but many are scarce and of conservation concern. Thinning may have significant negative effects, at least in the short-term, on invertebrates of soils and organic layers through soil compaction and disruption or loss of organic layers. Compaction will depend on soil type and thinning treatment. Soil organisms may be more protected than those in litter layers. Refugia (untreated areas from which populations can recolonize) are widely recommended to minimize effects of mortality and accelerate recovery of terrestrial invertebrates. Species such as root and bark beetles and wood borers that benefit from stress or weakened defenses of living host trees usually increase in the short-term to disturbance created by thinning and prescribed fire, but treatment timing affects responses. Several studies have shown that some bark beetles and wood borers increase less with thinning treatments than with prescribed fire, or with combinations of thinning and fire, probably due to fewer trees being injured with thinning. However, during periods of high infestation, injured and uninjured trees are equally likely to be attacked.

Removing woody biomass from a stand rather than letting it decompose onsite can affect soil chemistry, soil fertility and growth of residual plants. Decomposing wood helps replenish soil nutrients. But leaving excess forest biomass on the forest floor affects wildfire risk, and uncharacteristically severe wildfire can have a significantly negative impact on soil chemistry. Decisions of whether or not to remove woody biomass should be informed by the overall soil nutrient budget in a particular stand, including which nutrients are limiting. A 14-year study found that coarse woody debris does not appear to make a significant contribution to nitrogen and phosphorus levels in soils of three conifer forest types. Wood decay organisms may actually compete with vegetation for these limiting nutrients. This suggests that guidelines for coarse woody debris management in these forests should be based on objectives for other potential values (e.g. wildlife habitat) rather than its role in soil nutrient cycling. Undisturbed watersheds have little erosion but natural forests have natural disturbances, including wildfire and large floods, with return periods that range from decades to centuries.

Long-term natural background sediment yields from watersheds are a combination of low levels of erosion from undisturbed forests plus added erosion from occasional disturbances. Although undisturbed watersheds have little erosion, wildfire or flood can lead to significant upland erosion, and sediment deposition and movement in forest streams. Thinning activities are considered to be a disturbance. However, erosion rates associated with thinning are generally lower than from wildfire or flooding but may occur more frequently. Thinning and removal of small diameter wood and slash generally requires lighter equipment than traditional logging, but still entails some soil impacts.

These impacts must be weighed against potential impacts from uncharacteristically severe wildfires, and the potential benefits of thinning. Soil compaction can take decades to recover, reduces plant growth and inhibits water infiltration, which increases erosion, sedimentation and spring run-off. In some areas, compaction can be largely mitigated by conducting thinning operations on frozen and flood covered soil. Proper use of low-impact harvesting equipment and measures to utilize preexisting skid trails and avoid creating new ones can help maintain ecologically important soil properties in managed forest stands.

Erosion rates associated with woody biomass harvests are in general much lower than effects from wildfire or roads, but result in higher erosion levels than in undisturbed landscapes. Wildfire risk reduction if done appropriately can have long term positive effect on water quality, especially in areas of high fire risk like the Gambia.

The effects of forest biomass removal and use on air quality is a very complex topic, ranging from local smoke management concerns to national issues of carbon budgets, climate change and energy policy. Economically removing many small, non-merchantable trees from forests is the central dilemma in implementing fuel treatments. Leaving cut trees on the ground often increases fire hazard and the severity of pest insect outbreaks. This material is generally either burned in prescribed fires or in uncharacteristically severe wildfires that occur post thinning. Open burning of forest biomass in wildfires, prescribed fires, or slash burning can also impact forest ecosystems and produces large amounts of smoke, particulates, and significant quantities of nitrogen oxides, carbon monoxide and hydrocarbons that contribute to atmospheric ozone. Open burning also emit substantial amounts of carbon dioxide as well as methane and can impact human health. Quantifying emissions is difficult due to wide variation in fuels, burning practices and environmental conditions.

Use of woody biomass as an energy feedstock vastly reduces the smoke and a particulate emission associated with its disposal, and significantly reduces the amounts of carbon monoxide, nitrogen oxides and hydrocarbons released to the atmosphere. By one estimate, if no merchantable forest thinning were consumed in biomass power boilers instead of open burning, nitrogen oxides emissions could be reduced by 64% and particulate matter could be reduced by 97%. The U.S. Environmental Protection Agency estimates that emissions from biomass power plants are approximately 9 to 20% of emissions from open burning. Woody biomass power plants still emit large amounts of carbon dioxide, sometimes even in excess of fossil fuel plants because of lower combustion efficiencies for biomass.

However, carbon dioxide released by combustion of forest biomass was recently removed from the atmosphere through photosynthesis, and new plant growth will continue to remove carbon dioxide from the atmosphere after biomass is harvested . For this reason it is often argued that biomass is “carbon dioxide neutral.” However, power production from woody biomass involves other carbon flows, including fossil fuel burned during biomass harvesting, processing and transportation. Net carbon dioxide emissions from a biomass power plant are clearly lower than those from a fossil fuel plant, but the assumption that woody biomass power is currently a “carbon dioxide neutral” process should be tempered.

1 .6 .0 THE OBJECTIVES OF THE RESEARCH.

The purpose of this research is to conduct a biomass resource and bioenergy technology assessment for Gambia. This assessment will cover both forest biomass and agricultural residues. The Gambia forest are at high risk for wildfire, and the development of a bio energy facility would provide a market outlet for un-merchantable biomass and will provide much needed jobs and tax revenues in the local economy. This assessment will provide information that can help support the future development of biomass energy facility in the Gambia. The assessment will include information regarding optimal location for development of energy facilities in the Gambia, taking into account proximity to feedstock and existence of supporting infrastructures. Unlike any other energy resource, using biomass to produce energy is often a way to dispose of biomass waste materials that otherwise would create environmental risks. Using biomass for energy can deliver unique environmental dividends as well as useful energy in the following ways—[i] Reducing Greenhouse Gases—carbon dioxide and methane [ii] protecting clean water, [iii] keeping waste out of landfills,[iv] Reducing air pollution,[v] Reducing acid rain and smog and [vi] protecting forests.

1.7 .0 THE STUDY AREA.

The study areas will include the Greater Banjul region, Western Coast region, North bank region, Lower river region, Central river region and Upper river region of The Republic of the Gambia. The overall goal of this research will be to promote cost-effective sustainable biomass use for power and liquid fuel manufacturing in the Gambia.

To also identify potential sites in the region where a long-term, sustainable supply of biomass feedstock is available economically within a reasonable transportation distance from a potential plant.

The objectives of this research will be to

[a] conduct a review of previous related studies and assessments.

[b] evaluate the quantity of biomass produced in the Gambia.[c] conduct a preliminary sitting analysis and identify potential facility sites.[d]determine biomass availability and costs for delivery to potential sites in the Gambia.[e]develop biomass supply curves for each region in the Gambia.[f] identify issues associated with the sustainable use of biomass.[g]describe social, economic and environmental impacts of biomass energy use, and [h] discuss biomass facility characteristics and quantify feedstock requirements for hypothetical biomass power and cellulose ethanol plant to be developed in the Gambia.[i]provide information on best locations for potential biomass site in the Gambia [j]provide an overview of biomass energy technologies, feedstock requirements, and the economic potential to convert biomass to electricity or ethanol.

The overall approach to assessing the biomass resource is to first estimate the quantity of material generated from forestry and agricultural activities in the Gambia, Then taking into account technical and environmental constraints, the research would evaluate the quantity of material that could be recovered and made available for biomass energy uses.

1.8.0 RESEARCH PROBLEM.

This work is essentially an experimental, survey, data collection and analysis of biomass resources assessment and utilization, environmental effect of biomass removal and its impact on Gambia economy-specifically seeks answers to the following Problems.

[1] What are the effect of woody biomass collection and conversion on [a] plant resources,[b] wildlife,[c] soil resources,[d] water quality and [e] air quality

[2]How can biomass utilization affect forest sustainability in the Gambia.

[3]How can foresters optimize the benefits and minimize negative impacts of biomass collections and utilization in the Gambia.

[4]What legal, regulatory and economic issues affect the potential for biomass utilization in the Gambia.

[5]What site criteria limit the potential to collect and utilize crop residues. etc

[6] what are the effects of [a] emission of GHG from manure management and domestic livestock, savannah burning [bushfires],crop residue burning in the Gambia.[b] emission of non-co2 trace gas from agricultural soil.[c] estimation of co2 emission from changes on forest and other woody biomass stocks in the Gambia.

[7] what are the impact of climate change on [a] economic sectors and ecosystem,[b] habitat and species,

[c] forest resources in the Gambia

1.9.0 WORKING HYPOTHESIS.

[1] There is no significant relationship between Biomass resources Assessment /utilization and environmental effect of Biomass removal on Gambia economy.

[2] Environmental effect of Biomass removal has no significant impact on Gambia economy.

[3] There is no significant impact of Biomass resources Assessment /utilization on Gambia economy.

1.10.0 RESEARCH SCOPE AND METHODOLOGY.

Experimental, survey method, data collections and analysis method would be employed in conducting this research. The framework of this study would follow the following steps—[1] this will consist of forest cover classification and mapping, within Gambia [2] estimation of the available forest biomass and annual growth at national and regional level. [3] Complete data gathering and collection study for the industrial processes category in the Gambia to be able to extrapolate emission of GHG in the Gambia. The biomass resource in the study area consists of forest biomass, wood products manufacturing residue and agricultural crop harvesting residue.

Sources of forest biomass include forest fuels reduction projects; commercial timber harvest, non-commercial thinning and timber stand improvement activities.

Wood manufacturing residue consists of bark, sawdust, chips and veneer cores. Agricultural residue consists of straw, grass and leaves left over after harvesting the major crops in the region, which include grass seed, spring wheat, winter wheat, oats and barley. The overall approach to assessing the biomass resources is to first estimate the quantity of material generated from forestry and agricultural activities in the Gambia. Then, taking into account technical and environment constraints, the study will evaluate the quantity of material that would be recovered and made available for biomass energy uses.

Detailed information on local fuel consumption and local burning practices is required to construct a credible assessment of biofuel consumption and open field burning in the Gambia. This information is usually gathered in survey/questionnaire form. Reliable surveys are difficult to obtain: short term surveys frequently cannot account for seasonal fluctuations in- residue fuel availability [Hall and Mao, 1994]; surveys which describe rural village habits in one locale may not be adequate to describe the habits of rural communities located in different study regions within the country [Hosier, 1985]; surveys may not document factors which affect biofuel consumption such as fuel wood moisture content [Openshaw, 1986]. Difficulties in survey practice are discussed in detail in Hosier [1985] and Kgathi and Zhou [1995], while Openshaw [1986] provides guidelines for constructing comprehensive surveys of biofuel use. A significant amount of biomass that is not merchantable on traditional small-wood industries or for the manufacture of new wood products is available from forest in the regions study areas in the Gambia.

Biomass energy facilities [either stand-alone or integrated with an existing industrial facility] could provide a potential economic use for these materials. Feasibility depends on locating an energy facility close to the source of the materials and sizing the facility appropriate to the volume of material available on a long-term sustained basis. Using current and near-term technology, biomass energy facilities could convert surplus forest biomass into electricity, industrial steam energy and fuel ethanol. A barrier to private sector investment in biomass energy facility is the lack of specific information about the amount of biomass feedstock available, the cost of feedstock delivered to the plant site and the best locations for proposed facilities relative to both feedstock supply and markets for energy products. There is a critical need for this information in view of both high-fire risk in the forest and the need for economic stimulus in rural communitie

This research therefore addresses the goals of the Public Utility Regulatory Authority [PURA] of the Gambia by supporting the development of a locally-based biomass energy industry that would provide a long-term market for utilization of biomass materials resulting from fuels treatment projects on public lands. Information developed through this research will be needed to assess the economic feasibility of biomass energy development in the Gambia. Locally based facilities would benefit rural communities through on-site and in-forest job creation, local tax revenue potential and local economic activity associated with construction and operation. The Public Utility Regulatory Authority [PURA] of the Gambia supports the development of clean, reliable and affordable energy resources. This mission extends to the use of renewable energy resources, including biomass. This research will therefore promote utilization of sustainable, clean biomass resources and protection of Gambia natural resources.

1.11.0 PREVIEW OF SUBSEQUENT CHAPTERS.

CHAPTERS 2—REVIEW OF RELATED LITERATURE.

CHAPTER 4 —ANALYSIS OF DATA AND TEST OF HYPOTHESIS.

CHAPTER 5- FINDINGS, CONCLUSION AND RECOMMENDATIONS.

CHAPTER TWO.

2.0 REVIEW OF RELATED LITERATURE.

2.1 INTRODUCTION.

Biomass burning has a significant impact on global atmospheric chemistry since it provides large sources of carbon monoxide, nitrogen oxides, and hydrocarbons, primarily in the tropics [Crutzen et al., 1979, Logan et al., 1981]. These gases are precursors of tropospheric ozone and influence the chemistry of the OH radical [Logan et al., 1981; Logan, 1985]. Two notable components of biomass burning are the incineration of wood, charcoal and agricultural waste as household fuel, and the combustion of crop residue in open fields. As the developing world population continues to rise, the contributions from these types of biomass burning increase [Woods and Hall, 1994: hereafter referenced as WH94]. A quantitative description of the spatial distribution of biofuel and open field burning is required in order to assess the impact of this burning on the budgets of trace gases. Earlier estimates of global biomass burning were formulated using simple quantitative descriptions and generalizations. The burning of woodfuel was tied directly to forestry statistics published by the Food and Agriculture Organization (FAO) of the United Nations, while burning of agricultural residues in the developing and developed world was estimated as a fraction of the available residues [e.g., Seiler and Crutzen, 1980; Crutzen and Andreae, 1990; Andreae, 1991; Hao and Liu, 1994]. Since many factors such as geoclimatic conditions, vegetation distribution, farming methods, and population densities influence these types of biomass burning, simple global characterizations of these burning practices cannot provide reliable estimates. The purpose of this Research is to provide Gambia distributions that reflect major regional differences in biomass burning.

2.2 BIOMASS RESOURCE ASSESSMENT AND UTILIZATION.

Earlier studies [Seiler and Crutzen, 1980; Crutzen and Andreae, 1990; Andreae, 1991; Hao and Liu, 1994] used similar methods to calculate fuelwood use in the developing world, basing their estimates in some measure on the assumption that the production of fuelwood as given in the FAO Forest Products Yearbooks is equal to the fuelwood consumption, with modifications using additional data from surveys and estimates of per capita use. Their estimates vary from 620 to 1260 Tg dry matter for the developing world

Andreae calculated his estimate as the mean of the FAO fuelwood production and a mean estimate of per capita usage throughout the tropics of 1.3 kg/cap/day.

He suggested that using only FAO fuelwood statistics is likely to give low estimates since FAO considers only the marketed fuelwood production. A non-negligible portion of the fuelwood supply in the developing world is the wood debris which the rural populations gather for household fuel use [Openshaw, 1978] and which is not included in the FAO Yearbook estimates. Most previous studies provide a combined estimate for agricultural residues that are burnt as fuel and those that are burnt in the open fields to dispose of the stubble and to return nutrients to the soil. Seiler and Crutzen [1980] and Andreae [1991] proposed that 80% of available residues are burned in developing countries and 50% developed countries. Crutzen and Andreae [1990] suggested that 25% of crop waste is burned in the fields of developing countries in the tropics, while Hao and Liu [1994] assumed that 23% of residues are used as fuel and 17% are burned in the field.

The work of Hall and colleagues [WH94] has been seminal in shifting the focus of study of biomass combustion in the developing world from the use of woodfuels to a more comprehensive picture of ’biofuels’ combustion including the burning of crop residues and dung as fuels. Their estimates of biofuel use are based on the FAO fuelwood and charcoal estimates, the Biomass Users Network country studies, data from the U.N. Statistical Office, and, for countries which have little information available, on the following assumption: use of 2.74 kg/cap/day for rural populations and 1.37 kg/cap/day for urban populations [WH94]. Unfortunately, their study does not provide a breakdown by fuel type, nor is this breakdown easily determined [D. Hall, personal commmunication, May 1994]. By converting the other estimates to energy units we find that the WH94 figure of 49.9 EJ biofuels combustion for the sum of developed and developing world is almost one quarter again as large as the high end figure in the range of estimates of biofuel burning of Crutzen and Andreae [1990] (19.7-39.3 EJ)

Rural areas of developing countries depend primarily on biomass for fuel [Smil, 1979; Cecelski et al., 1979; Meyers and Leach, 1989; Leach and Gowen, 1987]. Biofuels include the woodfuels (fuelwood-- see Openshaw [1986] and charcoal), and agricultural waste, such as crop residues and dung. The amount of biofuel consumed varies as climate (higher consumption for colder climates) [Leach, 1988], and with the plenitude of fuel resource; where fuel is easily obtained, more is consumed [Meyers and Leach, 1989]. The choice of biofuel consumed depends on availability, local customs, and season [Meyers and Leach, 1989]. Generally, the sub-Saharan African population depends mainly on wood [Cecelski et al., 1979; Scurlock and Hall, 1990], as does the rural population in Latin America.

The population in Asia uses all biofuels [Cecelski et al., 1979, Meyers and Leach, 1989]. Biofuels are also major energy sources in the urban areas of the developing countries [Barnes et al., 2000]. In the developed world biofuels are important [Hall, 1991], but provide a smaller fraction of total energy consumed [WH94, Blandon, 1983]. Woodfuel is the principal source of domestic energy in developing countries [Openshaw, 1974, Eckholm, 1975, Arnold and Jongma, 1978, deMontalembert and Clement, 1983]. Woodfuel includes charcoal as well as firewood, brushwood, twigs, branches, and cut branches [Openshaw, 1986]. Where available, fuelwood is generally the biofuel of choice [Arnold and Jongma, 1978, Openshaw, 1986]. Climate and terrain are the two strongest natural influences on the growth and abundance of the forest resources, and these vary significantly throughout the developing world [deMontalembert and Clement, 1983]. Even in countries with adequate fuelwood supply, the resource may be located far from the more populated regions where it is needed [deMontalembert and Clement, 1983]. Alternative biofuels are used in regions lacking adequate fuelwood [Smil, 1979]. In countries where modern fuels are available and the rural population has the income to purchase them, fuelwood use is correspondingly lower [Cecelski et al., 1979.

A large fraction of urban populations in the developing countries relies on charcoal for cooking and industrial fuel [Barnes et al., 2000].. The carbonization process used in converting wood to charcoal is generally inefficient, and volatiles including CO2, CO, CH4, and non-methane hydrocarbons (NMHC) estimated at 60% by weight of the original wood are emitted [WH94]. Openshaw [1978, 1980, 1986] suggests that from six to twelve tons of wood are required to make one ton of charcoal. Nearly all of charcoal production occurs in the developing world [Lew and Kammen, 1994]. About half of the world’s charcoal is produced in Africa where it is used as a domestic fuel in many of the urban areas and as a cooking fuel in eastern and northern regions [Foley, 1986, Hibajene et al, 1993]. In Asia, the pattern of charcoal consumption varies from extensive use as a domestic fuel in both urban and rural Thailand [Foley, 1986, Ishiguro and Akiyama, 1995], and as a large industrial fuel for the steel industries in the Philippines and Malaysia [Foley, 1986], to a much smaller role in the domestic energy supply in India [Foley, 1986, Leach, 1987]. In Latin America charcoal is not a major household fuel, but is a notable source of energy for the steel industries of Brazil [Bogach, 1985, WH94], Bolivia, [World Bank (WB): Bolivia, 1994], and Paraguay [WB: Paraguay, 1984].

Billions of tons of agricultural waste are generated each year in the developing and developed countries. Agricultural residue includes all leaves, straw and husks left in the field after harvest, hulls and shells removed during processing of crop at the mills, as well as animal dung. The types of crop residue which play a significant role as biomass fuels are relatively few.

The single largest category of crops is cereals, with global production of 1800 Tg in 1985 [FAO, 1986a]. Wheat, rice, maize, barley, and millet and sorghum account for 28%, 25%, 27%, 10%, and 6%, respectively, of these crops. The waste products which are the main contributors to biomass burning are wheat residue, rice straw and hulls, barley residue, maize stalks and leaves, and millet and sorghum stalks. Sugar cane (0.95 gigatons) provides the next sizeable residue with two major crop wastes: barbojo, or the leaves and stalk, and bagasse, the crop processing residue. The cotton crop also gives non-negligible residue in the form of stalks and husks, both of which are used as biofuels. Four minor crops provide residue from processing that is frequently used as fuel: palm empty fruit bunch and palm fiber, palm shells, coconut residue, groundnut shells, and coffee residue. Geographical distribution of crop residue is skewed by large crop productions in India and China [FAO, 1986a]. The other countries of southeast Asia have rice and sugar cane as dominant crops. In the Middle East, the crop mixture is more diverse with more cereals and less rice and sugar cane. In the drylands of the Near East and Mediterranean northern Africa, wheat and barley predominate. In the sub-Saharan Sahel in Africa, millet and sorghum are the main crops. Farther south in the sub-humid and humid regions, maize is important. All three grains are grown in the highlands of eastern Africa. In Latin America, the crop residues of maize and sugar cane provide significant field and factory waste, with Brazil as the foremost contributor. Crop residue accumulates in the fields and in factories. The waste from the agro-processing industries accumulates at the mills where the crop is prepared for consumption. These include bagasse residue from sugar cane [WB: Ethiopia, 1986], rice husks, cottonseed hulls, palm, coconut, ground nut, cashew, and coffee processing waste. Agro-industrial biomass waste is used mainly as fuel for the processing industry, and is rarely transported any distance from the mills for other purposes [Barnard and Kristoferson, 1985, Openshaw, 1986]. It is generally unpalatable as fodder, and inaccessible, except locally, for household fuel.. The major field residues are sugar cane barbojo, and post-harvest grain residues as well as cotton stalks. Traditionally, the barbojo is burned in the fields as a pre-harvest measure to facilitate the harvesting of the sugar cane [Williams and Larson, 1993]. Cotton is a "woody" plant [Townsend, pc], a more likely substitute for fuelwood as household fuel, and a less likely fodder source. In addition, cotton is susceptible to a large number of pests and plagues [Percy, pc], so the cotton plants are destroyed after harvest to curtail the spread of pest and disease [WB: Burkina, 1986, WB: Ethiopia, 1984, Ramalho, pc, Valderrama, pc, Tothill, 1954, Matthews, pc]. The cotton stalks are either: mechanically destroyed and the leftover ploughed down [Hadar et al., 1993], as in many Latin American countries where tractors are more accessible [Ramalho, pc, Valderrama, pc, Cuadrado. pc, Jones, pc]; burned in heaps as in Africa where tractors are scarce [Tothill, 1954, Matthews, pc, Gray, pc, Poulain, 1980, Carr, pc];

or burned as fuel, as in several Asian countries where fuelwood substitutes are needed [Chaudry, pc, Townsend, pc].

Africa has the lowest per capita consumption of modern fuels in the developing world [Davidson, 1992]. Modern energy resources are concentrated in a few countries such as Nigeria, Libya, and South Africa [Kahane and Lwakabamba, 1990]. Most African countries are predominantly rural and economic output is low, so that the population cannot afford to buy oil-based fuels. The rural population (and often the urban population also [Cecelski et al., 1979, Barnes et al., 2000]) relies on wood and charcoal as the main fuels for domestic consumption [deMontalembert and Clement, 1983]

Africa is marked by contrasts in geo-climatic and vegetation conditions, from the northern drylands through the large desert and savanna zones with fuelwood deficits, to the forest zones with fuelwood surplus, to the more populous temperate eastern highland areas. Lack of infrastructure makes the transportation of wood from surplus to deficit regions difficult. The per capita woodfuel consumption depends on availability and demand, and ranges from an estimated low of 0.05 kg/cap/day in Lesotho to upwards of 3.0 kg/cap/day in Eastern Highland countries .

The Mediterranean countries of North Africa have more in common climatologically with the rainfed drylands of the Middle East than with sub-Saharan Africa. Fuelwood consumption is negligible in oil-rich states like Libya [deMontalembert and Clement, 1983] and modest in countries like Algeria, which, though a large oil-producer, has forested mountain zones and a sizeable low-income rural population .

The Sahel countries to the south are sparsely populated with desert and sub-desert mixed with savanna regions. Chad, which has desert in the north, and desertification and drought conditions in the south, has the lowest fuelwood consumption of 0.3 kg/cap/day. Mali, with its sufficient-to-surplus wood in western and southern regions [WB: Mali, 1991], but major woodfuel shortages in the three northeastern regions (identified using satellite data, 1[WB: Mali 992]) has the highest consumption of 1.49 kg/day. Sudan is an exception within this group in that its northern climate is desert, while its southern regions have tropical forests and savannas. The coastal countries of West Africa contain areas of wooded savanna and dense forest, with sparse to heavy population density. The fuelwood consumption estimates are mostly within the range of 1.3-1.7 kg/cap/day. Guinea, which has extensive forest cover and abundant fuelwood resources, is a notable exception, with 3.2 kg/cap/day [WB: Guinea, 1986]. The country which dominates fuelwood use in Africa, Nigeria, is included in this group, although its northern provinces are in the Sahel region.

My estimate for Nigeria is based on the Silvi-consult, Ltd survey (over 2350 households) of the five northern provinces [Hyman, 1994] and the very careful surveys of Kersten et al. [1998] in the Osun State of southern Nigeria. Kersten et al. [1998] found that even in the rural areas where an adequate supply of wood was available, there was low per capita consumption.

The countries of Central Africa have large zones of dense forest with low population density, and relatively high consumption rates, 1.5-2.5 kg/cap/day. Some countries such as Gabon and Equatorial Guinea are relatively prosperous [WB: Gabon, 1988] and their populations use substantial quantities of modern fuels in addition to woodfuels.

The highest fuelwood consumption rates occur in the highland countries of southeastern Africa, at 1.89 to 3.24 kg/cap/day, a consequence of plentiful forest resources and use of fuels for heating. Malawi [WB: Malawi, 1982], Uganda [O'Keefe, 1990], and Zambia [WB: Zambia, 1983] have extensive forest reserves. Kenya has productive forest land in the central highlands [Senelwa and Hall, 1993], and Tanzania has about 40% forest cover, much of this miombo woodlands [Hosier et al., 1990; WB: Tanzania, 1984].

Countries of the eastern and southern drylands region include sparsely populated savanna areas and dry mountainous zones of degraded forest cover [deMontalembert and Clement, 1983]. In many areas crop residues and dung are used as alternate fuels to supplement fuelwood, since fuelwood is scarce. Fuelwood consumption is fairly low, between 0.05 kg/cap/day in Lesotho and 1.84 kg/cap/day in Ethiopia, with an outlier of 2.04 kg/cap/day in Botswana. Within the island group there is a wide range of fuelwood consumption. The largest population inhabits Madagascar which is densely populated and whose fuelwood resources are being rapidly depleted. Five countries, Nigeria, Ethiopia, Tanzania, Kenya, and Zaire use 138 Tg/y of fuelwood or about 50% of the total for Africa . Usage varies from 1.50 kg/cap/day in Nigeria to 3.21 kg/cap/day in Tanzania. Ethiopia is classified in the Eastern/Southern Drylands region, but straddles the Eastern Highlands region; the per capita consumption of 1.84 kg/cap/day is somewhat high for the Eastern/Southern Drylands region. For Tanzania, Hosier et al. [1990] compared the results of four major reports on woodfuel balances, including Kaale [1983] on districts facing wood-deficit, Openshaw's [*1984*] analysis based on surveys in the 1970's, a World Bank ESMAP (Energy Sector Management Assistance Programme) [1984] assessment of the woodfuel-deficit regions, and Luhanga and Kjellstrom [1988] based on remote sensing information. Hosier et al. [*1990*] analyzed the differences in these studies and noted that, while different in detail for the twenty regions of Tanzania, their average estimates were remarkably similar.

Hosier [1985] compared the results of his survey of energy consumption in 1981 taken in rural households in different ecological zones of rural Kenya with the results of a 1978/1979 - 11 - survey among the same households. He noted that the average consumption rate of fuelwood had decreased from 2.44 kg/cap/day to 2.17 kg/cap/day.

Africa has the largest per capita charcoal use among the developing continents [Lew and Kammen, 1994]. The greatest per capita use is in the East African Highlands. These countries have a substantial wood supply which can be converted to charcoal and then transported to regions of demand. By contrast, little charcoal is used in the Southern Drylands. Urban users in Zimbabwe and Swaziland prefer firewood and coal [Hemstock and Hall, 1997]. No charcoal is produced in Botswana [Wisner, 1984]. In Lesotho [Frolich, 1984], Botswana [Hall and Mao, 1994], and Namibia [K. Openshaw, personal communication], the urban population uses firewood, kerosene, and coal. Sudan is unusual in that charcoal is significant as an energy source for both the urban and rural populations [Digernes, 1977; Craig, 1991]; almost 80% of the charcoal consumed in the Central Region is used by the rural population [Elgizouli, 1990]. Among the remaining countries, there are no obvious regional preferences. For West Africa, the urban populations of Burkina Faso, Mali [WB: Mali, 1991), and Niger prefer using firewood to charcoal, but the populations in the largest cities of Ghana use more charcoal [Foley, 1986]. Similarly, surveys indicate that city dwellers in Guinea [WB: Guinea, 1986], Togo [WB: Togo, 1985], Senegal [Lazarus et al., 1994; Foley and van Buren, 1982], and Sierra Leone [WB: Sierra Leone, 1987] are heavy charcoal consumers.

.Crop residue produced in Africa accounts for about 10% of the total agricultural residue in the developing world, [FAO, 1986a].About 80% of wheat and barley is grown in the rainfed drylands of the northern coast, while a similar fraction of millet and sorghum is grown in the sub-Saharan semi-arid Zone. Egypt, Madagascar, and Nigeria provide 62% of the rice residues in Africa, and Egypt and Sudan together produce 47% of the cotton residues. Maize is grown for the most part (about 75%) in the eastern countries of Africa, from Egypt south through the temperate highlands countries to, and including, South Africa. Most of the minor agro-industrial crop waste of palm (95%), coffee (56%), groundnut (50%), and coconut (40%) is produced in the tropical sub-humid and humid zones.

2.2.1 Rainfed Drylands Zone.

The residues of the wheat and barley grown in Mediterranean north Africa are generally used as livestock feed [Hadjichristodoulou, 1994; Whitman et al., 1989], similar to practices in the Near East In Algeria, barley is grown primarily for fodder [Tully, 1989]

. In Morocco, the cereal crop residue and barley crops are the main forage for the ruminant livestock [Tully, 1989; Fenster, 1989]. Once the residue has been harvested for winter feeding, the ruminants are allowed to graze the remaining stubble. I assumed 99% of the residues are used for fodder, and, as there is evidence of burning where livestock are few [United Nations Environment Programme, 1977], I arbitrarily assumed that 1% of residues are burned in the field before planting .

2.2.2 Semi-Arid SubSaharan Zone.

This zone with annual precipitation of 200-1000 mm/yr and frequent drought is a region of low biomass productivity, lacking forest cover. The major crops which can be grown without irrigation are millet, sorghum and cowpea [Christensen, 1994; Norman, 1981]; maize, groundnut, rice, and cotton are also grown. This region produces the most agricultural residue in Africa, in part because of the high residue to crop ratios from millet and sorghum and maize. As in the drylands zone, crop residues are a good source of feed for livestock, especially in the post harvest and dry seasons [Tothill, 1954: Norman, 1981; Lamers et al., 1996; McIntire, 1992; Sandford, 1989]. Crop residues are also needed as household fuel [Ernst, 1977]. Sorghum and maize stalks are important construction materials [Reddy, 1981; F. Harris, M. Mortimore, personal communication]. Whatever crop residue remains after these uses is either decomposed, eaten by termites [Ofori, 1989; Miracle, 1967], or burned in the open field prior to the planting season [Watts, 1987]. Livestock are integral to the lives of the farming and transhumant herder populations. In detailed aerial and ground surveys of land use covering 1.5 x 106 km2 in sub-Saharan Africa, a strong correlation was found between livestock density and the amount of cultivated land [Wint and Bourn, 1994]. While many tribesmen are exclusively stock owners, farmers who do not own any livestock are rare [Pingali et al., 1987; Mortimore, 1987; Dederi, 1990; Draft Report, 1986]. The rural population needs crop residues for both fuel and fodder [Alhassan, 1990; Umunna, 1990; Morgan, 1980]. In Burkina Faso [Sivakumar and Gnoumou, 1987], Mali [Dicko and Sangare, 1986], and Niger [Reed, 1992], reports provide evidence of large herds of cattle, sheep, and goats grazing post-harvest crop residues. While the importance of cereal residues as fodder is evident [Oyenuga, 1968], the task of quantifying this use is difficult. In Niger, farmers usually leave the residue of the millet crop in the fields for cattle to graze [Reed, 1992]. Measurements showed that 100% of the millet leaves and about 30% of the millet stems were eaten by cattle [McIntire, 1992]. In neighboring Nigeria, the main use of sorghum straw is for post-harvest and dry season animal feed [Alhassan, 1990, Umunna, 1990]. Studies on grazing habits indicate that in eight weeks after harvest, cattle graze almost all leaves, 47% of millet stalks and 40% of sorghum stalks [Powell, 1985]; another study suggests that passing ruminants graze 34% of the total edible sorghum residue left in the fields [van Raay and de Leeuw, 1971].

These data indicate that 30-43% of millet and sorghum residue collectively are grazed by cattle. Given that sizeable numbers of sheep and goats also graze in the semi-arid zone, I selected the upper end of the range, 43%, to represent the amount of millet and sorghum stalks used for fodder.

Straw and stalks in the semi-arid zone are used in construction of fences, houses, and compounds [Reddy, 1981; van Raay, 1975]. In this case, post-harvest millet and sorghum fields are burned rapidly to clear leaves: the stalks are then cut and bundled for construction use [WB: Benin, 1985]. As much as two-thirds of available sorghum stalks are estimated to be used for construction in Kano, Nigeria [F. Harris, p.c.]. On farms with no livestock, millet straw is often used as a mulch [Poulain, 1980]. I estimate that 20% of residue is used for construction, mulching, low-level decomposition in this dry region, and termite attack. A significant portion of crop residue in this zone is used for household fuel.

2.2.3 Sub-Humid Zone.

The sub-humid zone covers a band south of the semi-arid region through the center of west Africa and into east and southern Africa. This zone is better suited for agriculture, with 1000-1500 mm/yr rainfall [McIntire, 1992] and a growing period of six to nine months. A greater variety of crops is grown here with more maize and rice than in the semi-arid zone. However, this zone is less favorable for livestock, due to prevalence of trypanosomiasis and other livestock diseases [Areola, 1991; Sivakumar, 1987 Most countries, with the exceptions of Malawi and Ivory Coast, have sufficient wood for household use, so there is limited need of residues for construction or fuel.

2.2.4 Humid Zone.

This zone which extends along the coast of west and central Africa and through the Congo has heavy rainfall and a long growing season [McIntire, 1992]. Many different crops are grown, and here also, livestock numbers are low due to threat of stock diseases [McIntire, 1992]. Since forests and natural grazing lands are abundant, crop residue is not in great demand for either fuel or fodder. After the harvesting and some livestock grazing, the remaining residue decomposes in the fields for four to six months until March or April. The farmers then burn the leftover crop waste in the fields before planting [Watts, 1987; Miracle, 1967; J. Holtzmann, pc].

2.2.5 Highland Region.

The highland region has a temperate climate, good soils, and a long growing season [McIntire, 1992].

The cooler climate fosters a higher population density and also higher livestock density, as the threat of trypanosomiasis is almost nil [McIntire, 1992].

The high livestock count in the countries in this zone, Kenya, Ethiopia, Tanzania, Rwanda, and Burundi, suggests that much of the edible crop residue is used for animals [McIntire, 1992]. In addition to fodder, the residue is needed as household fuel. In Kenya crop residue is a commodity, bought or exchanged for plowing time, grazing land, etc. [McIntire, 1992; English et al., 1994]. Although Kenya has one of the highest rates of fuelwood use in Africa, Senelwa and Hall [1993] estimate that over 40 PJ (or, about 2.76 million tons) of crop residue (mainly sorghum and maize stalks) is used as household fuel In Tanzania the rural areas depend almost exclusively on wood for fuel, despite a number of wood-deficit regions in the country [Hosier et al, 1990 In contrast, there are many fuelwood deficit regions throughout Ethiopia [WB: Ethiopia, 1984], so that dung and crop residues are also used as household fuel.

2.3 ENVIRONMENTAL EFFECT OF BIOMASS REMOVAL.

This section reviews literature that includes information regarding the environmental effects of removing non-merchantable woody biomass – material from trees and woody plants, including limbs, tops, needles, leaves and other woody parts that are by-products of forest management, ecosystem restoration or hazardous fuel reduction treatments. Potential environmental effects of biomass removal are diverse, complex and inter-related, depending on forest type, pre-existing stand conditions, the timeframe being considered and the particular silvicultural prescription used. These changes can be either positive or negative in nature and can vary greatly in scale from site and stand-level to much larger spatial scales. Local to watershed-level effects include altered understory plant communities and wildlife habitat, changes in soil physical properties and chemistry, impacts on water quality and runoff patterns, changes in biodiversity and populations of individual species, and modified wildfire regimes. At larger spatial scales, woody biomass removal and conversion into products or energy can also affect carbon sequestration, atmospheric carbon emissions and climate patterns. The range of sources from which to draw information on the effects of woody biomass removal and conversion is similarly diverse and extensive. Rather than a comprehensive review, this research covers a sample of available, relevant literature, focusing primarily on local to water shed level environmental effects of biomass removal activities on forest ecosystems.

From an ecological viewpoint, it may be hard to distinguish between “woody biomass removal” associated with fuels reduction projects, and thinning treatments associated with traditional forest management focused on promoting vigorous tree growth.

Literature on the effects of silvicultural thinning treatments is much more voluminous than literature targeted specifically towards fuel treatments and non-commercial biomass removal. The research is laid out in sections that discuss effects on particular aspects of forest ecosystems- e.g. soil properties, water quality, wildlife, etc. Most of the available literature does not specifically examine the effects of removing biomass from the site, but focuses instead on the effects of opening up the forest canopy and impacts associated with mechanical fuel treatments. Many studies examine both thinning and prescribed fire and some combination of the two, but may not specify how thinned biomass is treated, specifically whether or not it is piled, burned, masticated, left onsite or removed.

A large body of research has demonstrated that, in general, thinning of densely stocked stands of conifers such as ponderosa pine and Douglas-fir improves the vigor of trees that are left in the stand by reducing competition for water and soil nutrients. Trees that are more vigorous are also less susceptible to insect attack. Indeed, improved tree health and growth, and resistance to insect attack are often key aspects of the rationale for thinning treatments. But thinning prescriptions involve more complex harvesting procedures than clear-cutting, and can result in damage to residual trees. Opening up the stand can also make residual trees more susceptible to wind-throw, and increase wind speeds, which in turn can affect fire behavior. This section summarizes some selected studies that investigated the effects of thinning on residual trees.

Since Euro-American settlement, forests in many inland western ponderosa pine-dominated forests have changed from open, low-density stands to closed, high-density stands, which has been detrimental to the vigor of old-growth trees. Stone and others (1999) examined whether the vigor of old-growth, pre-settlement trees could be improved by restoring the original stand structure through thinning of smaller trees that established after settlement. This treatment resulted in the following changes in pre-settlement trees and their environment in the first year following thinning: an increase in volumetric soil water content between May and August, an increase in predawn xylem water potential in July and August, a decrease in midday xylem water potential in June and August, an increase in net photosynthetic rate in August, an increase in foliar nitrogen concentration in July and August, and an increase in bud and needle size. These results show that the thinning restoration treatment improved the condition of pre-settlement ponderosa pines by increasing canopy growth and the uptake of water, nitrogen, and carbon. Kolb and others (1998) compared foliar physiology and several measures of tree resistance to insect attack among ponderosa pine trees growing in thinned stands.

The study area was a second-growth forest in northern Arizona, where four different density treatments (6.9, 18.4, 27.6, 78.2 m2 ha-1) have been experimentally maintained by frequent thinnings for 32 years before measurements began in 1994. Most of the physiological characteristics measured were affected by the basal area treatments. As stand basal area increased from 6.9 to 78.2 m2 ha-1, predawn water potential, midday water potential, net photosynthetic rate, resin production, phloem thickness, and foliar toughness decreased. Foliar nitrogen concentration was greatest in trees in the intermediate basal area treatments. Results indicated that the physiological condition of second-growth ponderosa pine can be improved by reducing stocking levels, and that dense stocking levels increase tree stress and decrease tree resistance to insect attack. Sala and others (2005) measured soil water and nitrogen availability, physiological performance and wood radial increment of second growth ponderosa pine trees in the Bitterroot National Forest, Montana, 8 and 9 years after four treatments: thinning only; thinning followed by prescribed fire in spring; thinning followed by prescribed fire in fall; and untreated controls. Trees of similar size and canopy condition in the three thinned treatments (with and without fire) displayed higher leaf-area-based photosynthetic rate, stomatal conductance and mid-morning leaf water potential in June and July, and higher wood radial increment relative to trees in control units. Results suggest that, despite minimal differences in soil resource availability, trees in managed units where basal area was reduced had improved gas exchange and growth compared with trees in unmanaged units. Interestingly, prescribed fire (spring or fall) in addition to thinning had no measurable effect on the mid-term physiological performance and wood growth of second growth ponderosa pine.

This section addresses effects of thinning and removal of forest biomass on plant communities in the forest understory. In general, opening up densely stocked stands increases understory plant biomass and biodiversity, which in turn increases habitat heterogeneity for wildlife. But newly available niches may also be colonized by invasive exotics. Kerns and others (2003) reviewed literature regarding the effects of forest management practices, including thinning and selection harvesting, on common Pacific Northwest understory non-tree species (i.e. shrubs, fungi, native mosses, lichens, ferns and herbs) with commercial, social or cultural value. Under-story species are also an important aesthetic component of forests. Kerns and others (2003) note that from the end of World War II until fairly recently, clear-cut logging and even-age management dominated forest practices in forests west of the Cascade Range, with the primary objectives of timber production and maintaining vigorous crop trees.

With this management legacy, the under-story in managed stands is generally an unintentional byproduct of timber management. Since the early 1990's there has been an increasing focus on alternative silvi-cultural systems and forest practices that embrace a broader range of values, including biodiversity and forest structural complexity.

At fine spatial scales, overstory stand structure strongly influences understory plant communities by controlling the amount of light that penetrates the canopy. Other factors that influence the composition of forest understories include the disturbance that originated the stand, the degree of biotic legacies (e.g. downed logs and surviving vegetation) retained following the disturbance, and the rapidity with which trees established on the site and formed a dense canopy.

Active management prescriptions that remove woody biomass can directly or indirectly alter rates and patterns of succession among understory species. If small conifer biomass is removed from the understory, the newly available habitat may be re-colonized by conifer seedlings, but is often colonized by other species – native and exotic. Removing biomass from the overstory influences understory species distribution and abundance by increasing light availability- a major limiting resource for most photosynthetic understory species in coniferous forests.

Most thinning operations are low to medium intensity disturbances compared to high intensity disturbances such as clearcut logging and stand-replacing fires. Thinning can increase microhabitats, creating new germination sites and small openings in the canopy. Light, water, nutrient availability and soil temperatures may increase. Therefore, thinning favors species that can rapidly colonize or expand into newly available resources, either by seeds or by vegetative propagation. Thinning intensity, frequency, stand age when thinned, uniformity of thinning and operational disturbance all influence understory species response. Uniform thinning leaves evenly spaced trees and usually a compositionally simple understory. Irregular or variable density thinning that creates openings and tree patches of different sizes can increase understory biodiversity.

Understory response to thinning, especially by shrubs, is typically correlated with the amount of canopy removed. With very light thinning, impacts of the initial disturbance may outweigh the benefits of making more resources available to understory plants. But heavy thinning with even spacing can reduce moisture availability due to increased wind and sunlight.

Metlen and Fiedler (2006) evaluated the effects of 1) no action, 2) thin-only, 3) spring burning, and 4) thinning followed by spring burning on the understory plant community in a second-growth western Montana ponderosa pine/Douglas-fir forest that initiated after harvest in the early 1900s and has not burned since. Treatments were implemented at an operational scale (~22 acres). Data were collected before and in each of three years after treatment, at two spatial scales: plot (1000 sq meters) and quadrat (1 sq meter). Treatments differentially impacted the understory plant community, most dramatically in the thin-burn. The burn-only treatment initially reduced understory richness and cover but by year three all active treatments increased plot-scale understory richness relative to pre-treatment and the control. Forbs, both native and exotic, were the most responsive lifeform and increased in richness and cover after thinning, with the greatest response in the thin-bum. Increased native species richness was not detected at the quadrat-scale in any treatment, but was significant at the plot-scale in numerous combinations of treatments and years. Short-term reduction in shrub richness and abundance after burning was detected at the quadrat-scale. Sapling density was reduced in all active treatments. Active treatments create more open overstories and increase understory diversity at the stand level, but a mix of treated and untreated areas will likely maximize heterogeneity and diversity at the landscape scale.

.This section addresses potential effects - positive and negative- of forest biomass removal on wildlife. Depending on local conditions and the specific prescriptions used, thinning and removal of biomass from dense, overstocked stands can often improve wildlife habitat, but not all species benefit and some may be negatively impacted. Pilliod and others (2006) refer to numerous studies on effects of prescribed fire, many of which assessed both fire and thinning effects simultaneously, and in ways that make it difficult to clearly differentiate between the two types of treatments. For this research, the focus is primarily on studies that address thinning effects, under the assumption that forest biomass utilization usually starts with thinning operations, but the biomass will be removed from the site rather than burned. Pilliod (2004) notes that managers face a difficult task in predicting the effects of fuel treatments on wildlife due to the paucity of information for most species and wide variability in habitat needs and responses, but suggests that predictions may be possible after considering an animal's ecology and then using available information in a conceptual framework that includes 1) species distribution and abundance, 2) migratory and dispersal characteristics, 3) habitat requirements and preferences, and 4) potential responses to changes in habitat.

.In most cases, conserving habitat heterogeneity also conserves biodiversity. Therefore, fuels treatment planners may want to coordinate with biologists to plan treatments that, over time, create a mosaic of forest structures and conditions that approximate natural disturbance patterns, which could be expected to support greater species diversity than large, homogeneous stands given the same treatment.

Treating fuels in habitat patches adjacent to untreated patches that are occupied by a given wildlife species may increase the rate of colonization and recovery compared to restoring areas at random. (Pilliod and others 2006.)

A species' response to habitat changes from fuels treatment depends on habitat elements that species needs to survive and reproduce, and how the treatment affects these habitat elements. Potential effects of a fuels treatment on a particular species should be considered within the context of that species' distribution and abundance, migratory and dispersal characteristics, habitat associations, and potential responses to habitat changes. If a species is widely distributed, localized fuels projects may have relatively minor effects on population viability, depending on the species' ability to recolonize from surrounding areas. But for species with a limited distribution, especially in cases where an entire subpopulation of a rare species lies within the treatment area, it may be necessary to protect specific habitat components or leave untreated refugia within project boundaries. (Pilliod and others 2006.)

Species responses may also vary over time. For example, the population of a small mammal species that requires shrub cover to avoid predators may decline following treatment, but then later exceed pretreatment levels when shrubs recover and food resources increase from greater light, herbaceous growth and seed production that result from opening up the forest canopy. (Pilliod and others 2006.)

Most forest carnivores are relatively rare, and there are substantial information gaps on their responses to tree harvest. Because most have relatively large ranges, few forest carnivore species will be affected by stand-level fuels projects. But some could be affected by loss of denning habitat and changes in prey populations due to cumulative effects of past management, past disturbances and larger scale projects (Pilliod 2006). Both marten and fisher are sensitive to loss in canopy cover and are strongly associated with downed wood cover. These are both indicator species, which can complement ecosystem-level conservation planning by revealing thresholds in habitat area and landscape connectivity (Carroll and others 2001). Black bears are more common than most other forest carnivores and their diet and habitat may be influenced by fuels projects. Black bears use areas with abundant down wood and dense thickets of shrubs and smaller trees adjacent to or within mature forests. About 25% of black bear diet can consist of insects (mainly ants and yellowjackets) obtained primarily from down logs (Bull and others 2001), so decreases in down wood can make less of this food available to black bears.

Black bears also strip bark from smaller trees and feed on sapwood. In a western larch, lodge pole pine and Engelmann spruce forest in northwestern Montana, black bear feeding on sapwood was 5 times higher in thinned stands where bears mostly selected 5”-10” larch trees compared with adjacent unthinned stands (Mason and Adams 1989). The health and condition of residual trees may have attracted the bears. Treated stands may also provide dependable food sources for bears when fruit, mast, grass, and herbaceous plant production increase after prescribed fire. But fuel treatments may reduce the amount of escape cover, perhaps the most critical component of black bear habitat (Hamilton 1981). Sites used by black bears for traveling and resting typically have high stem density and dense canopies, presumably for security. Bears use large-diameter hollow logs for denning (Bull and others 2000) that may be lost in thinning operations.

The more open understories created by fuel treatments may benefit hawks, owls, and eagles that prey on small mammals and birds in open forests and small clearings because prey species that have less cover are more easily captured. (Pilliod and others 2006.).Removal of trees with dwarf mistletoe brooms during thinning will likely be detrimental to raptor species that nest in the brooms including the great gray owl, long-eared owl, great horned owl, northern spotted owl, northern goshawk, Cooper’s hawk, and red-tailed hawk (Bull and others 1997). Northern goshawks prefer closed canopy forests of large-diameter trees with relatively open understories (Reich and others 2004). Management recommendations for sustaining northern goshawk habitat and prey include thinning from below to achieve nonuniform spacing of large trees, a maximum of 30 to 50% canopy opening, and various slash treatments (Reynolds and others 1992, Squires and Reynolds 1997). The endangered Mexican spotted owl and northern spotted owl both occur in dry forest environments. Management guidelines for both species specify little active management in defined areas. By reducing the risk of stand-replacing fires in these defined areas, restoration treatments outside of these areas should benefit spotted owls over time (Beier and Maschinski 2003). Variable-density thinning may accelerate development of northern spotted owl habitat and dense prey populations (Carey 2001, 2003, Carey and others 1999a, b; Carey and Wilson 2001; Muir and others 2002), especially when snags, cavity trees and large downed wood are conserved (Bunnell and others 1999; Carey 2002; Carey and others 1999a, b) though this treatment may be more appropriate in mixed conifer stands with mixed-severity fire regimes than in drier pine, low-intensity fire regimes (Lehmkuhl and others 2006). Fuel treatments may reduce northern spotted owl habitat quality, but this should be weighed against the risk of stand replacing fires and complete loss of habitat over large areas (Everett and others 1997).

Reptile diversity is generally lower in forests than in deserts, grasslands, and chaparral. Few lizard and snake species occupy western closed canopy coniferous forests except for perhaps the rubber boa. But reptile species do inhabit specific forest patches, such as wetlands, meadows, and rock outcroppings that provide shelter, microclimates, and prey (Heatwole 1977, Lillywhite 1977) including the western fence lizard, eastern fence lizard, sagebrush lizard, ornate tree lizard, western skink, northern alligator lizard, garter snakes, mountain king snake, racer, gopher snake and western rattlesnake. Very little is known about the effects of thinning on reptiles, and Pilliod and others (2006) found no studies specific to dry coniferous forests. Reptile species that prefer forest floor cover might decrease when such habitat is lost, but most reptile species would probably benefit from reduction in shrubs, ground vegetation, and litter cover and depth (Germaine and Germaine 2002; Knox and others 2001; Mushinsky 1985; Singh and others 2002). Many lizard species prefer snags and down wood over live trees (James and M'Closkey 2003), so fuel treatments that leave snags and down wood on site may improve habitat for these species.

Most forest amphibians use upland habitats at various times during the year, depending primarily on the availability of moist duff and litter and rotting down wood. Unlike reptiles, amphibians' response to reduced canopy cover will likely be negative due to warmer, drier conditions created in the understory vegetation, down wood, litter and soil (McGraw 1997, Meyer and others 2001, Pough and others 1987). Most terrestrial salamanders require moist soils or decomposing wood to maintain water balance, therefore dry conditions usually result in suppressed populations (Bury and Corn 1988, deMaynadier and Hunter 1995). Frogs and toads may be less affected by environmental changes associated with fuel treatments because they tend to travel at night and during rain events, their greater mobility compared to salamanders, and their close association with wetlands (Constible and others 2001, Pilliod and others 2003). Still, species that frequently occupy terrestrial habitats, including many salamanders, boreal toads, and tree frogs may be killed during fuel treatments or find post-treatment conditions unsuitable (Pilliod and others 2003).

Fuels treatment effects on terrestrial invertebrates in western dry coniferous forests- insects, spiders, mites, scorpions, centipedes, millipedes, isopods, worms, snails and slugs- are probably as diverse as the group itself. Invertebrates comprise over half of the animal diversity in forests (Niwa and others 2001), occupy all forested habitats and have varied functional roles including detritovores, predators, herbivores and pollinators. Many invertebrates are specifically associated with habitat elements targeted in fuel treatments, e.g. shrubs, snags, litter, and duff. Most invertebrates occupy distinctly different habitats during their life cycles. For example, some species live below ground when young and above ground as adults or feed on vegetation as immatures and then on flower nectar as adults.

This section addresses the effects of thinning and forest biomass removal on forest soils- one of the primary concerns cited by conservation groups regarding biomass removal activities.

Thinning and removal of small diameter wood and slash generally requires lighter equipment than traditional logging projects, but active harvesting of any kind generally entails some degree of soil impact. A key consideration is weighing the physical soil impacts of management activities to remove small diameter wood against impacts that can result from uncharacteristically severe wildfires that may occur if stands are left untreated.

Removing thinnings and slash from a stand rather than leaving it onsite to decompose can also affect soil chemistry. Decomposing wood helps replenish soil nutrients. But managers must also consider how leaving excess forest biomass on the forest floor affects fuel loadings and wildfire risk- uncharacteristically severe wildfire can also negatively impact soil qualities. Whether or not removing biomass negatively effects soil fertility and growth of residual plants depends on the overall soil nutrient budget in the stand, and which nutrients are limiting.

Brown (2000) discusses a primary challenge with understory thinning- the low value of the wood that is usually targeted for removal encourages use of low-cost harvesting methods. This typically means ground-based equipment, which can seriously degrade forest soils. Soil is not only the fundamental source of productivity in forest ecosystems, but also strongly influences hydrologic function and water quality. Soil compaction, which can take decades to recover, reduces plant growth and also inhibits infiltration of water, which increases erosion, sedimentation and spring run-off. Fire can also adversely affect forest soils, but Brown (2000) maintains that these effects are relatively short-lived. McIver and others (2003) examined fuel reduction by mechanical thinning and removal in mixed-conifer stands in northeastern Oregon in an experiment that compared a single-grip harvester coupled with either a forwarder or a skyline yarding system, and unharvested control sites. Both extraction systems achieved nearly equivalent (~46%) mass fuel reduction. Of 37 logged hectares, 1.4% (0.5 ha) of the soil area was compacted, mostly within forwarder units, log landings, and trails close to landings. Displaced soil varied from 5 to 43% area among units and was located within trails or in intertrail areas between the trails. Elliot and Miller (2002) used the Water Erosion Prediction Project (WEPP) model to compare erosion rates from fuel management operations, including roads, to erosion following wildfire for climates across the western U.S. Forest sediment yields were estimated with the Disturbed WEPP online forest erosion prediction interface, an adjunct to the WEPP model that allows users to easily describe numerous disturbed forest and rangeland erosion conditions. The interface presents the probability of a given level of erosion occurring the year following a disturbance.

All scenarios assumed that if no harvesting occurred, the area would progress to the point of a high severity fire. No scenarios were examined for undisturbed conditions (neither harvesting nor fire occurrences). All thinning and prescribed fire simulations retained 85% surface cover as recommended by most Forest Service regional soil quality guidelines. The wildfire scenario assumed a 45% cover. Results indicated that erosion from fuels treatment operations, including thinning and prescribed fire, are less than from wildfire, even when road erosion rates are included. Forest erosion rates from the wildfire scenario were predicted to be about 40 times the erosion rates from prescribed fire with buffers. Erosion due to thinning was predicted to be about 70% that of prescribed fire, or 1% that of wildfire. Nitrogen (N) is a critical limiting nutrient that regulates plant productivity and the cycling of other essential elements in forests. Johnson and Curtis (2001) performed a meta-analysis of forest management effects on soil carbon (C) and nitrogen (N). Results indicated that that forest harvesting, on average, had little or no effect on soil C and N. But significant effects of harvest type and species were noted. Leaving residues on site (i.e., sawlog harvest) caused an 18% increase in soil C and N whereas residue removal (i.e. whole tree harvesting) caused a 6% decrease compared to controls. The positive effect of sawlog harvesting appeared to be restricted to coniferous species, although reasons for this were not clear. Conversely, several studies from widely varied conditions clearly showed that residues had little or no effect on soil C or N in hardwood or mixed forests. Johnson and Curtis (2001) include a discussion regarding harvesting residues: “Several studies found that soil C and N temporarily increase after sawlog harvesting, apparently a result of residues becoming incorporated into the soil. The general trends found in a number of these studies, however, are consistent with the concept of high C/N ratio residues becoming incorporated into soils over the short-term with soil C re-equilibrating to lower levels and to C/N ratios more similar to background as time passes. This raises other questions regarding C balances. Specifically, what is the long-term fate of the residues? They remain part of the O [organic] horizon for long periods in some cool coniferous forests but in warmer hardwood forests, they rapidly decompose. If leaving residues on site has no long-term positive effect on mineral soil C, removing residues for biomass burning may be more C efficient (by offsetting fossil fuel combustion) than leaving them on site. Conversely, nutrients left behind in residues may result in long-term carbon gains in aboveground vegetation and cause residue removal to be less C efficient. If the latter is true, how do the C and economic costs of fertilization compare with the costs of leaving residues on site?

The effects of noncommercial forest biomass removal and utilization on air quality is a complex topic that ranges from local-level smoke management concerns to national and international scale issues of carbon budgets, climate change and energy policy. This section addresses some of the issues and tradeoffs that policymakers and planners are faced with as they consider how to move forward,

Finding economically viable ways remove huge numbers of small, non-merchantable trees from the landscape is the central dilemma facing managers as they try to implement hazardous fuel treatments. One option is to simply cut these trees and leave them on the forest floor. However, doing so often increases fire hazard and the severity of pest insect outbreaks. Historically this material was either burned in prescribed fires or in uncharacteristically severe wildfires. But high fuel loadings, air quality restrictions, short windows of appropriate weather, and risk of escaped fire are some factors that limit application of prescribed fire (USDA Forest Service 2003). Within its natural range, wildfire has a number of beneficial effects on forest ecosystems, and both prescribed fire and wildland fire use are viable and useful tools for managers. On the other hand, open burning of forest biomass – whether in wildfires, prescribed fires, or slash burning – can have detrimental impacts on forest ecosystems and produces large amounts of visible smoke, particulates, and significant quantities of nitrogen oxides, carbon monoxide and hydrocarbons that contribute to the formation of atmospheric ozone. Wildfires also emit substantial quantities of carbon dioxide (CO2) as well as methane, and other trace gases (Morris 1999; McNeil Technologies 2003) and can impact human health. Quantification of emissions is difficult because of extreme variability in fuels, burning practices and environmental conditions (Morris 1999). Converting biomass waste into energy is one promising way to sustainably address some of these problems. Use of biomass waste as power plant fuel vastly reduces the smoke and particulate emissions associated with its disposal, and significantly reduces the amounts of carbon monoxide, nitrogen oxides, and hydrocarbons released to the atmosphere. By one estimate, if non-merchantable forest thinnings were consumed in biomass power boilers instead of open burning, nitrogen oxide emissions could be reduced by 64% and particulate matter could be reduced by 97% (Antares Group, Inc. 2003).

Particulate matter emissions from open burning depend on the amount of fuel and type of fire, generally ranging from 25 to 40 pounds per ton of fuel burned. Estimates of fuel burned per acre range from 11.0 tons for a prescribed fire in a low-density stand to 79.5 tons during a high intensity wildfire in a high-density stand (Sampson and others 2001). Resulting emissions therefore could range from 275 to over 3,000 lbs. per acre burned. Estimates of emissions from biomass power plants by the EPA include 0.22 – 0.3 lbs. per MMBTU of fuel input (United States Environmental Protection Agency 1995). This equates to 3.7 – 5.1 lbs. per ton of fuel, or 9 to 20% of the emissions from open burning.

Use of biomass fuels produces lower emissions than coal-fired plants, so to the extent that biomass replaces coal use, air quality will benefit. Biomass is lower in sulfur than is most U.S. coal. Typical biomass contains 0.05 wt % to 0.20 wt % sulfur on a dry basis. In comparison, coal has 2 wt % to 3 wt % sulfur on a dry basis. Biomass sulfur content translates to about 0.12 to 0.50 lb of sulfur dioxide per million BTUs. Using biomass to generate power typically produces lower sulfur dioxide emissions than using coal. Nitrogen oxide emissions should also generally be lower for biomass, due to lower fuel nitrogen content and the higher volatile fraction of biomass versus coal.

The McNeil Technologies (2003) report also addressed the complex issue of the “carbon footprint” of forest biomass energy in comparison to fossil fuels. Biomass power plants can produce large emissions of carbon dioxide (CO2), sometimes even in excess of fossil fuel plants because of lower combustion efficiencies for biomass. However, the CO2 released by combustion of forest biomass was removed from the atmosphere in the recent past through photosynthesis and new plant growth will continue to remove CO2 from the atmosphere after biomass is harvested. For this reason it is often argued that biomass is “CO2 neutral.” In practice, the picture is somewhat more complex. Other carbon flows are involved with biomass power production, including CO2 emissions from fossil fuel burned during harvesting, processing and transportation operations. Net CO2 emissions from a biomass power plant are clearly lower than those from a fossil fuel plant, but under current production practices, biomass power is not a net zero CO2 process.

2.4 CONCLUSION.

The purpose of this chapter is to examine related literatures surrounding the sustainability of biomass use in the study area, in part to ensure that biomass use is consistent with environmental quality objectives and potentially to broaden outlet markets for biomass power to include “green” or “environmentally friendly” power and fuel products. Task efforts included the development of sustainability criteria based on input from local stakeholders provided via a regional sustainability focus group. Estimates of biomass generation and availability incorporated a variety of criteria to ensure that biomass utilization did not hurt land productivity, watershed health or forested areas that have legal, regulatory or planning restrictions on management. Forest biomass generation estimates are from projects implemented on state, tribal,/municipal and other lands that have undergone all necessary legal, regulatory and planning processes. Forest biomass availability estimates take into account the need to use some biomass to prevent soil disturbance on project sites.

Agricultural residue supply estimates incorporate restrictions on the quantity of residue that can be removed without damaging land productivity or water quality.

CHAPTER 3

3.0 DATA COLLECTION AND PRESENTATION.

3.1 INTRODUCTION.

Experimental, survey method, data collections and analysis method would be employed in conducting this research. The framework of this study would follow the following steps—[1] this will consist of forest cover classification and mapping, within Gambia [2] estimation of the available forest biomass and annual growth at national and regional level. [3] Complete data gathering and collection study for the industrial processes category in the Gambia to be able to extrapolate emission of GHG in the Gambia. The biomass resource in the study area consists of forest biomass, wood products manufacturing residue and agricultural crop harvesting residue. Sources of forest biomass include forest fuels reduction projects; commercial timber harvest, non-commercial thinning and timber stand improvement activities. Wood manufacturing residue consists of bark, sawdust, chips and veneer cores. Agricultural residue consists of straw, grass and leaves left over after harvesting the major crops in the region, which include grass seed, spring wheat, winter wheat, oats and barley. The overall approach to assessing the biomass resources is to first estimate the quantity of material generated from forestry and agricultural activities in the Gambia. Then, taking into account technical and environment constraints, the study will evaluate the quantity of material that would be recovered and made available for biomass energy uses.

An assessment of the Gambia resource base for biomass production is performed. Estimates of recoverable biomass material available for energy production were made for the major agricultural field crops of groundnuts, rice and maize. The potential use of high yield perennial grasses and wood for energy production was also examined as a means to diversify the supply of biomass resources and to estimate their economic value. Because the availability of agricultural residues was changing over the course of this analysis,it must be noted that estimates of recoverable biomass are generally higher than what is actually available for use. As well, during the course of this analysis a more precise and detailed local assessment of the biomass resources of the Gambia was undertaken (PBEL, 2001).

The formulas used in this research for developing the potentially recoverable biomass can be used to get an updated assessment as crop production levels change and to assess potentially recoverable biomass resources in a region or near a biomass conversion plant.

Biomass resources considered in this Research included:

- Agricultural crop residues (corn stover and small-grain straws, including wheat, barley,
- Animal fats and waste greases (beef tallow, yellow grease)
- Forest biomass resources
- Mixed grass species crops (short-rotation woody crops (SRWC) and herbaceous)
- Orchard and vineyard trimmings (apples, almonds, grapes, etc.)
- Biosolids
- Grain and oilseeds (corn, soy, and canola)

3.2 METHOD OF DATA COLLECTION.

The process used to identify, screen and rank potential conversion sites in the study area would be discussed. The sites identified within each region of the Gambia were screened for appropriateness as potential conversion sites, and then sites were ranked to identify one potential candidate site within each region. In each region, there were multiple sites that could be suitable, and the differences between some sites are minimal. Consideration would be given to alternative sites should a detailed engineering evaluation be conducted in the future.

Detailed information on local fuel consumption and local burning practices is required to construct a credible assessment of biofuel consumption and open field burning in the Gambia. This information is gathered in survey/questionnaire form. Reliable surveys are difficult to obtain: short term surveys frequently cannot account for seasonal fluctuations in residue fuel availability [Hall and Mao, 1994]; surveys which describe rural village habits in one locale may not be adequate to describe the habits of rural communities located in different geoclimatic regions within the Gambia [Hosier, 1985]; surveys may not document factors which affect biofuel consumption such as fuel wood moisture content [Openshaw, 1986] Energy assessments for The Gambia conducted by the World Bank (WB) and the United Nations Development Programme (UNDP) provided another source material used in this analysis.

These reports give information on the available energy supplies, with data obtained from government sources and/or from surveys conducted by the researcher in the six regions of the Gambia.. They usually include an annual energy balance which contains estimates for use of fuel wood, charcoal, and other agricultural residues as fuel. The quality of information varies, depending on the accuracy of the government sources, and the nature of the surveys [Openshaw, personal communication; Openshaw, 1986].

The second sources comprise individual reports for the six regions of the Gambia. The information in these research ranges from direct quotations of governmental energy statistics on biofuel use to descriptions of very careful surveys which included many participants, extended through several seasons and several locations/ministries to provide a comprehensive database for analysis.

Agricultural statistics usually published as government documents give details on quantities of crops and livestock distributed within the provinces or regions of the Gambia . Various treatises on biological processes were consulted to ascertain modes of biomass decomposition in differing climatic conditions. Other botanical statistics were examined to determine more information about crop growing, processing and consumption practices in the Gambia. Specific information on crop residue use was frequently included.

Also, discussions with personnel in the groundnuts and rice processing industry, agronomists, botanists, and foresters, and others with experience in the Gambia yielded a plethora of anecdotal evidence providing personal observation on burning practices indicative of large-scale burning activities within some regions of the Gambia..

The focus in this research is on the approach and methodology used in biomass energy assessments. The methodology is crucial when analysing the differences between biomass energy assessments because the methodology determines to a large extend the possibilities and limitations when investigating biomass energy assessments, but also the level of detail, accuracy, completeness, scope and data used in the analyses.

Biomass resources in the Gambia, such as urban wood waste, forest residues, forest thinnings, and others, can be used to generate renewable energy, reduce greenhouse gas emissions, improve forest health, and provide economic benefits to rural communities. The feasibility of bio energy (i.e., energy generated from biomass) projects depends largely on the availability of woody biomass resources.

More specifically, it is the economic availability or total delivered price for a given quantity, rather than just the physical availability, that is relevant to the development of bio energy projects.

Most assessments of biomass availability to date estimate the total amount of biomass within a given straight-line radius and assume average production costs for the area. A more comprehensive economic assessment of biomass resources takes into account that costs vary with biomass type, distance, and transportation infrastructure. When transportation costs are taken into account, more costly resources in close proximity may be economically competitive with cheaper resources farther away, and vice versa.

Most resource-focussed studies use comparable methodologies to estimate the potential of energy crops. In resource-focussed studies the production of energy crops is limited to surplus areas of agricultural land, i.e. land that is no longer required for the production of food and that is also not needed for other purposes (e.g. for the protection of biodiversity or for infrastructure). The amount of surplus agricultural land is calculated based on statistical analysis or sometimes spatially explicit analysis.

In Siemons et al. (2004) a statistical analysis of technical biomass energy potentials in the Gambia to 2020 was estimated, whereby the availability of land for energy crops production is limited to set aside land. Also in Thrän et al. (2006) a statistical analysis is applied, whereby the availability of surplus agricultural land for energy crop production in the Gambia in the year 2020 is estimated based on a region by region evaluation of food consumption, crop yields and efficiency with which animal products are being produced. In addition, various scenarios are compiled for the demand for biomass energy, which are compared with the technical biomass energy supply to estimate biomass energy trade flows. This methodology clearly shows the limitations of estimating the technical potentials of biomass energy.

In Siemons et al. (2004) the statistical assessment of technical biomass energy potentials is supplemented by an evaluation of the economic-implementation potential. This is evaluated using the Strategic Assessment Framework for the Implementation of Rational Energy (SAFIRE) model, which is an engineering-economic bottom-up supply and demand model for the assessment of energy technologies (renewable and new non-renewable). Five distinct progressive steps are distinguished:

1 energy consumption
2 technical potentials
3 decentralised market potentials
4 market penetrations
5 cost benefit calculations.

The cost benefit calculations are based on the calculation of the payback period of each fuel, those biomass technology combinations with the best payback period will be installed and subsequently start generating renewable energy. This methodology can be classified as a feasibility and impact assessment.

In Perlack et al. (2005) a statistical and cost supply assessment is also applied. The goal is to evaluate the feasibility of a supply of biomass equal to 30% of the Gambia gasoline consumption. The potential from agriculture (conventional crops and perennial crops) is estimated using various assumptions on productivity increases for which scenarios are included. In Gordon et al. (2008a; 2008b; 2008c; 2008d) a spatially explicit analysis of the potential production of grasses, in which only agricultural lands are included that have suitable characteristics (precipitation, slope gradient and elevation). The results are used in conjunction with an infrastructure system cost optimisation model to develop biofuel supply curves using biomass feedstock throughout the Gambia. This is a unique aspect of this research, which is not found in any other research work that are investigated. Also the costs of bio energy conversion technologies are investigated. The end result is a road map that shows what is technically and economically feasible and what is needed to increase the usage of alternative fuels. The results also identify the steps to diversify transportation fuels, energy sources, increase the transportation fuel efficiency, and increase domestic production of transportation fuels.

In the study ‘Estimating the environmentally compatible bio energy potential from agriculture’ (EEA 2007), that was carried out by the European Environment Agency (EEA) the results of several models are used as input and a statistical analysis was used. A partial equilibrium agricultural-economics model, called the Common Agricultural Policy Simulation (CAPSIM), was used to calculate the area of surplus agricultural land in the EU 28 in the year 2030. The CAPSIM model is adjusted to take various environmental variables into account, such as an increase of the area of environmentally oriented farming from the present 3% to 30% in the year 2030. The model excludes the impact of the additional use of biomass energy; the model only simulates the future use of agricultural land in the EU, based on a set of assumptions of population growth, income growth, technological developments and the Common Agricultural Policy (CAP). Another model, called HECTOR (an acronym for the Hektar-KalkulaTOR) was used to calculate the impact of the price of fossil energy and GHG emission permits on the production and prices of food and on land use.

HECTOR is not a complete economics model, so it only partially covers the economic mechanisms behind land use change.

Several studies use partial or complete equilibrium models to estimate the contribution of biomass energy to the energy supply mix. Examples are the ‘World Energy Outlook’ (WEO) studies from the International Energy Agency (IEA 2005; IEA 2006; IEA 2007; IEA 2008). In the WEO studies an energy sector partial equilibrium model, called World Energy Model (WEM), is used, which provides short- to medium-run energy demand and supply projections made up of 21 regional or country blocks. The WEM is made up of six main modules: final energy demand, power generation, refinery and other transformation, fossil fuel supply, CO2 emissions, and investment. The main exogenous assumptions concern economic growth, demographics, international fossil fuel prices and technological developments. A key disadvantage is that the projected use of bio energy is not validated based on data about the availability and productivity of land for energy crop production.

The problem of data validation is partially resolved in the VIEWLS and REFUEL project. In VIEWLS and REFUEL cost-supply curves are used as input in a linear optimisation energy model, called the Perspectives on European Energy Pathways (PEEP) model. The PEEP model has three end-use sectors: electricity, transportation and heat and other fuel use. The model has three main parts: (i) the supply of primary energy sources, (ii) the supply of energy-conversion technologies producing energy carriers, (iii) and the final energy demand. A complementary analysis is conducted which investigates whether different policy objectives underlie the promotion of biomass resources in Europe (cost-effective climate change mitigation, employment creation and reduced dependency on imported fuels). However, in both studies the economic linkages between energy use and land use change are still rather static.

Furthermore, energy models are especially suitable to investigate the costs and economic potential of biomass energy in relation to other energy sources, but these models do not account for the impacts on food and fibre markets. For that, agricultural economics models can be used. Examples are the IMPACT model (Von Braun 2007) and the Aglink model that are operated by the OECD (2006). These models estimate the impact of biomass energy on agricultural markets, and to some extent food security. They also model competition for other production means, such as labour.

An important limitation of the agricultural economics models is that the results are not usually verified with bottom up information on land use patterns, attainable crop yields and so forth.

A study that incorporates both the economic mechanisms of land use change, as well as bottom-up information on the agro-ecological limitations of crop growth, is the Eururalis study (Eickhout and Prins 2008) and the Scenar 2020 study (Scenar2020 2006).

3.2.1 Components for Calculating Economic Availability.

Assessing the economic availability of biomass requires information about production costs and the physical availability of biomass resources in the area of interest. The methods used are composed of the following three components , calculation of transportation costs and haul times, determination of physical availability and geographic distribution of biomass, and creation of biomass resource supply curves. The delivered cost of woody biomass can be defined as the sum of procurement (i.e., the amount paid to gain ownership of a biomass resource), harvest, and transportation costs. This requires assembling procurement and harvest cost assumptions for different types of biomass resources and calculating transportation cost as a function of haul time. GIS is an efficient and useful tool for evaluating woodshed procurement areas and transportation costs (e.g., Young et al. 1991, Brewington et al. 2001, Chalmers et al. 2003). Assessing transportation cost based on haul time rather than distance accounts for site specific road infrastructure and geographical constraints within a woodshed.

3.2.2 Calculating Haul Time.

Determining the proportion of each region in The Gambia within a given haul time category was the first step. Haul times were calculated to account for road infrastructure. Using the Field Calculator in ArcMap, speed limits were assigned to road features in The Gambia Census TIGER shape files and road lengths were divided by speed limits to estimate travel time. The Service Area function in the ArcGIS Network Analyst extension was used to calculate service areas based on travel time and the proportion of each region. Each haul time category was based on a 15-minute interval. The procedure for calculating haul times by generating service areas with ArcGIS Network Analyst can be used for specific locations of biomass drop-off such as bio energy generation facilities.

For the six[6] regions of the Gambia in the study, the delivery point was calculated using the Centroid function of Xtools Pro 3.2, a third-party extension to ArcGIS from Data East, an ESRI business partner and international distributor. The area of interest (AOI) was defined as regions within the maximum potential extent of the woodshed defined as a 45 kilometre (or 28-mile) radius to include greater than a two-hour one-way haul. Using ArcToolbox, the TIGER country roads shape files were merged and projected into the appropriate regional Plane coordinate system for each AOI.

The Field Calculator was used to assign speed limits to road features based on the attribute census feature class codes in Gambia Census TIGER shape files, and road lengths were divided by speed limits to estimate travel time. Haul time was increased by 25 percent to account for operational delays. Service areas are calculated based on haul time in 15-minuteintervals using the ArcGIS Network Analyst Service Area Calculator. The resulting service area polygons are exported as shape files. Service area polygons were combined with regions polygons using the Union function and clipped to the area of interest. A new floating point field called New Area was added. The new area for each feature in the service area-region union was calculated. A text field called Con-Cat was added, and regional identifier field (FIPS) was concatenated with the service area haul time field (To-Break) to create the FIPS-To-Break field. A table summary was performed based on the Con-Cat field to include the original area average and the sum of the New Area field. The summarized table was imported to Microsoft Excel so the percentage of each regions in each haul time category could be calculated by dividing the New Area field by the original area for each FIPS-To-Break record. This area percentage was used to estimate the percentage of each biomass resource type by each haul time category in each region. An Excel pivot table was used to calculate the estimated total of each biomass resource in each haul time category. The procurement, harvest, and transportation costs were summed to calculate the total delivered cost of each woody biomass resource within a given haul time category. Ranking these resource haul time categories from lowest cost to highest cost yielded the estimated progression of most to least economically available woody biomass resources. Under these cost assumptions, urban wood waste requiring a one-way haul up to 30 minutes is cheaper than other woody biomass resources with shorter haul times.

3.2.3 SUPPLY CURVE CONSTRUCTION USING EXCEL.

With the information on quantities, distribution, procurement, harvest, processing, and transport costs for each woody biomass resource, supply curves can be constructed. A supply curve is a basic economic tool used to express the price of a resource at a given quantity of demand. Supply curves can be plotted in Microsoft Excel as a scatter plot or by using the Macro Economic Supply Curve Chart Excel add-in. Supply curves were plotted so that the x-axis was the cumulative total amount of woody biomass with each additional resource-haul time category and the y-axis was the total delivered cost. Units were expressed based on energy content of the biomass; however, these could have been expressed as units of mass.

Availability of carbon in Gambia forests for use as a biomass fuel varies with site quality and management objectives.

Acknowledging this, my approach began with establishing the range of site indexes and collecting information on current fuels reduction and forest restoration management practices on the Gambia forest. I used two methods to develop estimates for the amount of carbon that is currently available.

The first method used the Forest Vegetation Simulator (FVS) forest growth model to grow forward Gambia forestry inventory data until specified management criteria were met and simulated thinning consequentially took place. The carbon removed in each of these thinning was tallied by stand and the means of the collective stands were reported. This method most accurately reflects existing conditions on the Gambia forest reserve. The second method relies solely on the FVS model and simulates the growth of hypothetical stands under the same management and thinning criteria. Although the second method does not reflect specific stand conditions observed on the Gambia forest, it does effectively show how an even-aged, planted stand will perform. Both methods utilize custom calibration factors that fine tune growth rates to the Gambia forest reserves..

3.2.4 The Forest Vegetation Simulator

The Forest Vegetation Simulator (Dixon 2003) is an individual tree and stand level growth and yield model that is based on the Prognosis model (Stage 1973). The Prognosis model was developed in 1973 for the Northern Rocky Mountains, and the need for a similar model specific for other country of the world like the Gambia in west Africa quickly became apparent. Extensions to Prognosis began in 1978, and GENGYM (Edminster et al. 1991), today known as the “Central Rockies Variant”, was developed in 1991. Like the Prognosis model, the Central Rockies Variant is a set of allometric equations that defines growth rates for tree species in New Mexico, Arizona, and South Dakota. This variant is broken into five sub-variants. The sub-variant specific to the sub-saharan Africa like The Gambia was used to generate the information in this research.

Management Practices

Current management guidelines in the Gambia Forest for fuels reduction and forest restoration involve reducing standing forest biomass (current basal areas range from 90 – 140 ft2/acre) to a target basal area of 40 – 60 ft2/acre. This guideline is based on research done by Merrill Kaufmann and others (Kaufmann et al. 2000, Kaufmann et al. 2001, Romme et al. 2003).

Inventory data acquisition

The following steps were used to download inventory data for both calibrating the

FVS model and estimating the amount of standing biomass greater than 3 inches in diameter:

1) Stand inventory numbers were sorted into relevant site index groups (45, 55, 65, and 75). Using site index groups, stand identification numbers from the RIS database query were used to download specific stand exams using the FSVeg database. These specific stand exams remained grouped by site index.

2) The grouped inventory data was manually checked and corrected to ensure that FSVeg reported the same information as the RIS database.

3) Grouped inventory data was then input into the FVS program to create calibration factors and to model forest biomass accumulation for each site index.

Model Calibration

The FVS system was calibrated specifically for conditions found on the Gambia forest. Stand exams completed in the area between 2000 and 2010 were used in the FVS system to adjust growth rates by using the CalbStat and ReadCorD keywords.

CalibStat uses increment core data to generate growth rate (calibration) statistics for each stand exam. These individual stand statistics are then averaged and tested for significant difference from the default values loaded in the program. A two-sided t-test determined that a significant difference exists for both the ponderosa pine and lodgepole pine models. Ponderosa pine diameter growth was increased by a factor of 1.363 and Lodgepole pine was decreased by a factor of 0.603 . ReadCorD was used to input the adjusted growth rates into the FVS system.

3.2.5 Calculating Removable Carbon – Method 1

Method 1 used the Forest Vegetation Simulator (FVS) forest growth model to grow forward each group of stand exams until specific management criteria was met and simulated thinning consequentially took place. Each site index group (45, 55, 65, 75) was loaded into the FVS model and processed separately. For each of these groups, the FVS model was set up to grow to 6 different basal areas (90, 100, 110, 120, 130, and 140 ft2/acre).

Thus, the model simulates the full spectrum of present site conditions on the Gambia forest.

Each distinct basal area was thinned to three post-treatment basal area targets (40, 50 and 60 ft2/acre). These values encompass the range of possible management targets that a manager may chose, given the flexibility in potential management practices. The ThinBBA keyword was used in the FVS model to fulfill the pre-treatment growth criteria and the post-treatment basal area targets,. The ThinBBA keyword initiates a thinning from below to a specific basal area target. In our model runs, the ThinBBA keyword was used as part of an if/then statement which allowed the thinning to only take place after the forest stand had grown to a specified basal area (ex. 90, 100, 110, 120, 130, 140). To track overall forest growth and fuel accumulation in the simulated stands during pre- and posttreatment periods, keywords FuelOut, Summary, and DSNOut were used in conjunction Biomass Removal and Carbon - 7 with the FVS Database Extension. The FVS Database extension allows desired outputs to be placed into a Microsoft Excel Spreadsheet which aids in data analysis. FuelOut generates a forest fuels report and the Summary keyword requests a report of all stand condition per growth cycle. These reports were generated for each stand in each group. DSNOut is used to specify the Excel Spreadsheet filename where these reports are to be sent.

3.2.6 Calculating Removable Carbon – Method 2

Method 2 relied solely on the FVS model to simulate the growth of hypothetical stands until the same management criteria were met and thinning took place. This was accomplished by running Bareground stands in FVS. Bareground stands provide a blank slate where the FVS user defines all stand components for the FVS run, particularly site index, planting density and onsite woody debris. Onsite woody debris defaults were set to zero using the FuelInit keyword. I designed the runs as in Method 1. Stands in four site index groups (45, 55, 65, 75) were grown to six pre-treatment basal areas (90, 100, 110, 120, 130, 140). Site indexes for each group were defined using the SiteCode keyword. Thinning targeted three post-treatment basal areas (40, 50, 60) for each group-basal area combination. Planting density was established using the Planting and Natural Regeneration tool. I used three planting densities (300, 450, and 600 trees per acre) for each run to compare the growth performance of each density. For young stands whose age was greater than 30 and basal area was less than 80, 20 trees per acre per 10 year cycle were established as ingrowth (Wayne Sheppard, USDA Forest Service RMRS Silviculturist, personal communication). Available carbon was reported as a mean of these three densities. The ThinBBA keyword was used as part of an if/then statement to define pre-treatment and post-treatment basal area targets. To track overall forest growth and fuel accumulation in the simulated stands, keywords FuelOut, Summary, and DSNOut were used in conjunction with the FVS Database Extension. This allowed outputs to be produced a excel spreadsheet where post processing took place.

3.2.7 Post Processing- Calculations

The researcher uses the FuelOut and Summary keywords with the FVS Database Extension to generate excel spreadsheets containing a fuels report and summary growth statistics for each stand. FVS tallies relevant statistics in growth cycles of 10 years. Summary statistics (containing basal area) are tallied at the end of each cycle. The if/then statement related to thinning is then evaluated at the beginning of the next cycle. If the statement is true and the stand basal area is greater than or equal to the pre-treatment basal area target (90, 100, 110, 120, 130, 140), FVS thins the stand to the defined post-treatment basal area target (40, 50, 60). If the statement is false, the stand completes an additional growth cycle and is evaluated again at the beginning of the next cycle. The > 3 inch live wood column in the fuels report represents wood biomass that can be easily removed from a forest stand. To calculate removed biomass from thinning, one must subtract the pre-treatment biomass, Biomass Removal and Carbon - 8 from the post-treatment biomass. Because growth is assessed in 10 year increments, stands often exceed their basal area targets. This is overcome by manually calculating the pretreatment biomass. The basal area and >3” live, woody biomass from the cycle prior to that in which the thinning took place was applied to the equation below:

RBT = (PreBio + (BAT – PreBA)* Bio/BA) - PostBio

RBT = Removable biomass from thinning (>3” live woody pool)

PreBio = Pre-treatment biomass (>3” live woody pool)

BAT = Basal area target

PreBA = Pre-treatment basal area

Bio/BA = Biomass per basal area unit

PostBio = Post-treatment biomass (>3” live woody pool)

To calculate carbon content in the removable biomass from thinning, fifty percent of biomass was assumed to be carbon (Schlesinger 1997). Carbon dioxide equivalent was calculated by multiplying the amount of total carbon over all pools by 3.67 (Chicago Climate Exchange, Inc. 2004, US Department of Energy 2007).

GAMBIA MAP.

3.3 DESCRIPTIVE DATA.

This section of the research discusses two approaches for estimating the biomass density of woody formations based on existing forest inventory data. The first approach is based on the use of existing measured volume estimates (VOB per ha) converted to biomass density (t/ha) using a variety of "tools" (Brown et al. 1989, Brown and Iverson 1992, Brown and Lugo 1992, Gillespie et al. 1992). The second approach directly estimates biomass density using biomass regression equations. These regression equations are mathematical functions that relate oven-dry biomass per tree as a function of a single or a combination of tree dimensions. They are applied to stand tables or measurements of individual trees in stands or in lines (e.g., windbreaks, live fence posts, home gardens).

The advantage of this second method is that it produces biomass estimates without having to make volume estimates, followed by application of expansion factors to account for non-inventoried tree components. The disadvantage is that a smaller number of inventories report stand tables to small diameter classes for all species. Thus, not all study region in the Gambia are covered by these estimates. There is no way to extrapolate from inventories that do not measure all species. To use either of these methods, the inventory must include all tree species.

Use of forest inventory data overcomes many of the problems present in ecological studies. Data from forest inventories are generally more abundant and are collected from large sample areas (sub-national to national level) using a planned sampling method designed to represent the population of interest. However, inventories are not without their problems. Typical problems include:

(a) Inventories tend to be conducted in forests that are viewed as having commercial value, i.e., closed forests, with little regard to the open, drier forests or woodlands upon which so many people depend for non-industrial timber.

(b) The minimum diameter of trees included in inventories is often greater than 10 cm and sometimes as large as 50 cm; this excludes smaller trees which can account for more than 30% of the biomass.

© The maximum diameter class in stand tables is generally open-ended with trees greater than 80 cm in diameter often lumped into one class. The actual diameter distribution of these large trees significantly affects aboveground biomass density.

(d) Not all tree species are included, only those perceived to have commercial value at the time of the inventory.

(e) Inventory reports often leave out critical data, and in most cases, field measurements are not archived and are therefore lost.

(f) The definition of inventoried volume is not always consistent.

(g) Very little descriptive information is given about the actual condition of the forests, they are often described as primary, but diameter distributions and volumes suggest otherwise (e.g., Brown et al. 1991, 1994).

(h) Many of the inventories are old, 1970s or earlier, and the forests may have disappeared or changed.

Despite the above problems, many inventories are very useful for estimating biomass density of forests. The method presented here is based on existing volume per ha data and is best used for secondary to mature closed forests only, growing in moist to dry climates.

It should be used for closed forest only because the original data base used for developing this approach was based on closed forests.

The primary data needed for this approach is VOB/ha, that is inventoried volume over bark of free bole, i.e. from stump or buttress to Crown Point or first main branch. Inventoried volume must include all trees, whether presently commercial or not, with a minimum diameter of 10 cm at breast height or above buttress if this is higher. If the minimum diameter is somewhat larger, the VOB/ha information can be used with some adjustments as shown below. However, such adjustments to the primary data introduce larger errors in the estimate.

3.3.1 GENERAL EQUATION

Biomass density can be calculated from VOB/ha by first estimating the biomass of the inventoried volume and then "expanding" this value to take into account the biomass of the other aboveground components as follows (Brown and Lugo 1992):

Eq. 3.2.1

Aboveground biomass density (t/ha) =VOB*WD*BEF

Where;

WD =Volume-weighted average wood density (1 of oven-dry biomass per m3 green volume)

BEF = biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume).

Wood density here is defined as the oven-dry mass per unit of green volume (either tons/m^3 or grams/cm^3). Wood densities for trees of tropical American forests tend to be reported in these units. In contrast, few data on wood density for trees in tropical Africa and Asia are expressed in these units (Reyes et al. 1992). Rather, wood density is expressed in units of mass of wood at 12% moisture content per unit of volume at 12% moisture content. A regression equation was developed by Reyes et al. (1992) to convert wood density based on 12% moisture content to wood density based on oven-dry mass and green volume (Eq. 3.2.2).

Eq.3.2.2

$$Y = 0.0134 + 0.800X$$

(r^2=0.99; number of data points n =379)

Where;

Y=wood density based on oven dry mass/green volume.

X =wood density based on 12% moisture content.

Ideally, a weighted average (based on dominance of each species as measured by volume) wood density value is best used here, calculated as follows.

Eq.3.2.3.

$WD =\{(V_1/V_t *WD_1 + (V_2/V_t) *WD_2 + \ldots\ldots\ldots (Vn/Vt)*Wdn$

Where;

$V_1,V_2 \ldots\ldots Vn$ = volume of species 1,2…..to the nth species

V_t =total volume WD_1 WD_2 ……Wdn = wood density of species 1,2,…to the nth species.

However, sufficient wood density data of forest species to do such calculations are not always available. In these situations it is best to estimate a weighted mean wood density based on known species, using an arithmetic mean from the table below for unknown species. Wood density data for 1180 tropical tree species are given in the table below.

The arithmetic mean and most common wood density values (t/m^3 or g/cm^3) for tropical tree species by region

Tropical region	No. of species	Mean	Common range
Gambia	282	0.58	0.50-0.79
West coast region	470	0.60	0.50-0.69
North bank region	428	0.57	0.40-0.69

(from Reyes et al. 1992)

Biomass expansion factor is defined as: the ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10 cm or more to the oven-dry biomass density of the inventoried volume. Such ratios have been calculated from inventory sources for many broadleaf forest types (young secondary to mature) growing in moist to seasonally dry climates throughout the tropics. Sufficient data were included in these inventory sources to independently calculate aboveground biomass density and biomass of the inventoried volume (Brown et al. 1989). The reported inventoried volume in the research was based on the definition given above. Analysis of these data show that BEFs are significantly related to the corresponding biomass of the inventoried volume according to the following equations (Brown and Lugo 1992):

Eq.3.2.4

BEF =Exp{3.213-0.506*Ln(BV)} for BV <190t/ha

1.74 for BV> =190t/ha

Sample sizes, 56 adjusted r^2 =0.76

Where

BV =biomass of inventoried volume in t/ha, calculated as the product of VOB/ha(m^3ha) and wood density (t/m^3)

No model for calculating biomass expansion factors for native conifer forests is available at present because of the general lack of sufficient data for the type of analysis performed for the broadleaf forests. However, one would expect that BEFs for tropical pine forests would vary less than for broadleaf forests because of the generally similar branching pattern exhibited by different species of pine trees. Biomass expansion factors have been calculated based on a limited data base of 12 stands of Pinus oocarpa growing in Guatemala (Peters 1977) and the methodology given in Brown et al. (1989). The inventoried volume in this case was defined as volume over bark/ha from the stump to the tip of the tree; i.e. main stem based on total height. Volumes of these stands ranged from 64 to 331 m^3/ha. The BEFs based on biomass of the main stem ranged from 1.05 to 1.58, with a mean of 1.3 (standard error of 0.06). No significant relationship between BEF and main stem biomass was obtained. Until additional data become available, a BEF of 1.3 can be used, with caution, for biomass estimation of pine forests.

3.3.2 EXAMPLES OF CALCULATIONS OF BIOMASS DENSITY

To demonstrate the application of this methodology, aboveground biomass density is calculated for the following examples:

Example 1*.*

Broadleaf forest with a VOB = 300 m^3/ha and weighted average wood density; WD = 0.65 t/m^3

<u>Step 1</u> Calculate biomass of VOB: = 300 m^3/ha x 0.65 t/m^3 = 194 t/ha

<u>Step 2</u> Calculate the BEF (Eq. 3.1.4): BV > 190 t/ha, therefore BEF = 1.74

<u>Step 3</u> Calculate aboveground biomass density (Eq. 3.1.1): = 1.74 x 300 x 0.65

= 338 t/ha

Example 2*.*

Broadleaf forest with a VOB = 150 m^3/ha and weighted average wood density,

$WD = 0.55\ t/m^3$

Step 1 Calculate biomass of VOB: = 150 m^3/ha x 0.55 t/m^3 = 82.5 t/ha

Step 2 Calculate the BEF (Eq. 3.1.4): BV < 190 t/ha, therefore BEF = 2.66

Step 3 Calculate aboveground biomass density (Eq. 3.1.1): = 2.66 x 150 x 0.55

= 220 t/ha

As can be seen from these two examples, although there is a two-fold difference in VOB/ha, there is only a 1.5-fold difference in aboveground biomass density.

Forest inventories often report volumes to different standards, e.g., to minimum diameters greater than 10 cm. These inventories maybe the only ones available, and thus it is important that a means to unify the volume data to some kind of standard be developed so that these inventories can be used to estimate biomass density.

In an attempt to unify data on inventoried volume measured to a minimum diameter greater than 10 cm, volume expansion factors (VEF) were developed (Brown 1990). After 10 cm, a common minimum diameter for inventoried volumes ranges between 25-30 cm. Data from inventories that reported volumes to minimum diameters in this range were combined into one data set to obtain sufficient number of studies for analysis. The VEF is defined here as the ratio of inventoried volume for all trees with a minimum diameter of 10 cm and above (VOB_{10}) to inventoried volume for all trees with a minimum diameter of 25-30 cm and above (VOB_{30}). The uncertainty in extrapolating inventoried volume based on a minimum diameter of larger than 30 cm to inventoried volume to a minimum diameter of 10 cm is likely to be large and is not suggested. Estimates of the VEFs were based on a few inventories from tropical Asia and America which provided sufficient detail for this analysis (see Brown 1990). Volume expansion factors based on these inventories ranged from about 1.1 to 2.5, and they were related to the VOB as follows:

Eq.3.2.5

$VEF = Exp\{1.300-0.209*Ln(VOB)\}$ for VOB <250 m^3/ha =1.13 for VOB>250m^3/ha

Sample size =66, adjusted r^2=0.65

To demonstrate the use of this correction factor to estimating biomass density, consider the following example:

Broadleaf forest with a VOB = 100 m^3/ha and weighted average wood density; WD = 0.60 t/m^3

Step 1 Calculate the VEF from Eq. 3.1.5: = 1.40

Step 2 Calculate VOB: = 100 m^3/ha x 1.40 = 140 m^3/ha

Step 3 Calculate biomass of VOB: = 140 m^3/ha x 0.60 t/m^3 = 84 t/ha

Step 4 Calculate the BEF from Eq. 3.1.4: BV < 190 t/ha, therefore BEF = 2.64

Step 5 Calculate aboveground biomass density (Eq. 3.1.1): = 2.64 x 140 x 0.60

= 220 t/ha

No general approach for estimating aboveground biomass density of open forests and woodlands based on inventoried volume has been developed because of the general lack of suitable data. The method described above for closed forests is not generally applicable because trees have different branching patterns (often multi-stemmed) and inventoried volume of open forests and woodlands is usually measured to different standards than for closed forests. For example, inventories done in open forests and woodlands generally report inventoried volume per ha to minimum diameters less than 10 cm, and also often include branch volume. Earlier work suggested that total aboveground biomass density of open forests could be up to three times the inventoried volume (Brown and Lugo 1984), however further field testing would be needed to confirm this. It is recommended that the approach described below for estimating aboveground biomass density be used for open forests and woodlands.

Another estimate of biomass density is derived from the application of biomass regression equations to stand tables. The method basically involves estimating the biomass per average tree of each diameter (diameter at breast height, dbh) class of the stand table, multiplying by the number of trees in the class, and summing across all classes. A key issue is the choice of the average diameter to represent the dbh class. For small dbh classes (10 cm or less), the mid-point of the class has been used (e.g., Brown et al. 1989). The quadratic-mean-diameter of a dbh class would be a better choice, particularly for wider diameter classes. If basal area for each dbh class is known, the quadratic-mean-diameter (QSD) of trees in the class, or the dbh of a tree of average basal area in the class, should be used instead. To calculate the QSD, first divide the basal area of the diameter class by the number of trees in the class to find the basal area of the average tree. Then the dbh = 2 x {square root (basal area/3.142)}. For example, the dbh of a tree of basal area of 707 cm^2 = 2 x {square root (707/3.142)} = 30 cm.

The biomass regression equations for broadleaf forests were developed from a data base that includes trees of many species harvested from forests from all three tropical regions (a total of 371 trees with a dbh ranging from 5 to 148 cm from ten different sources; see equation 3.2.2 in the table below was developed by Martinez-Yrizar et al. (1992)). The biomass regression equations can provide estimates of biomass per tree.

The data base was stratified into three main climatic zones, regardless of species: dry or where rainfall is considerably less than potential evapotranspiration (e.g. <1500 mm rain/year and a dry season of several months), moist or where rainfall approximately balances potential evapotranspiration (e.g. 1500-4000 mm rain/year and a short dry season to no dry season), and wet or where rainfall is in excess of potential evapotranspiration (e.g. >4000 mm rain/year and no dry season). These rainfall regimes are just guides, and generally apply to lowland conditions only. As elevation increases, as in mountainous areas, temperature decreases as does potential evapotranspiration and the climate zone becomes wetter at a given rainfall. For instance, an annual rainfall of 1200 mm in the lowlands would be the dry zone, but at about 2500 m it would be the wet zone. Therefore, judgement should be used in selecting the appropriate equation.

Figure 1

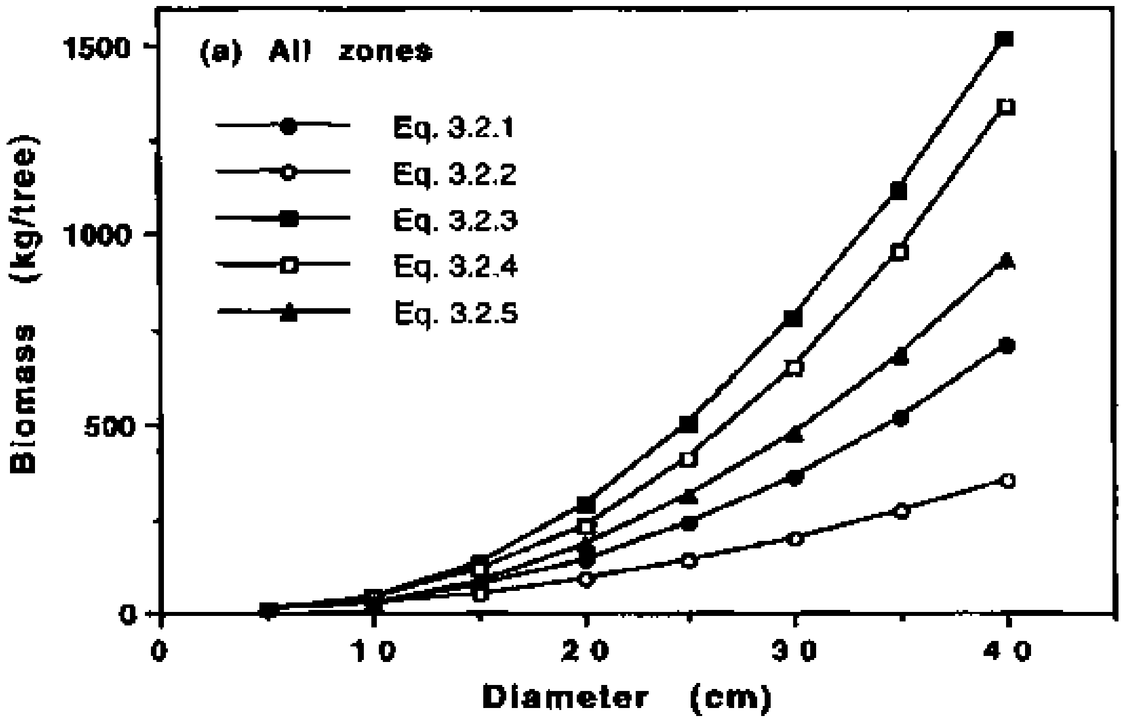
Relationship between oven-dry biomass of tropical trees and dbh for-

(a) Biomass regression equations by all climatic zones and trees with dbh between 5 to 40 cm, and

(b) Equations for moist and wet zones for trees in the full range of dbh.

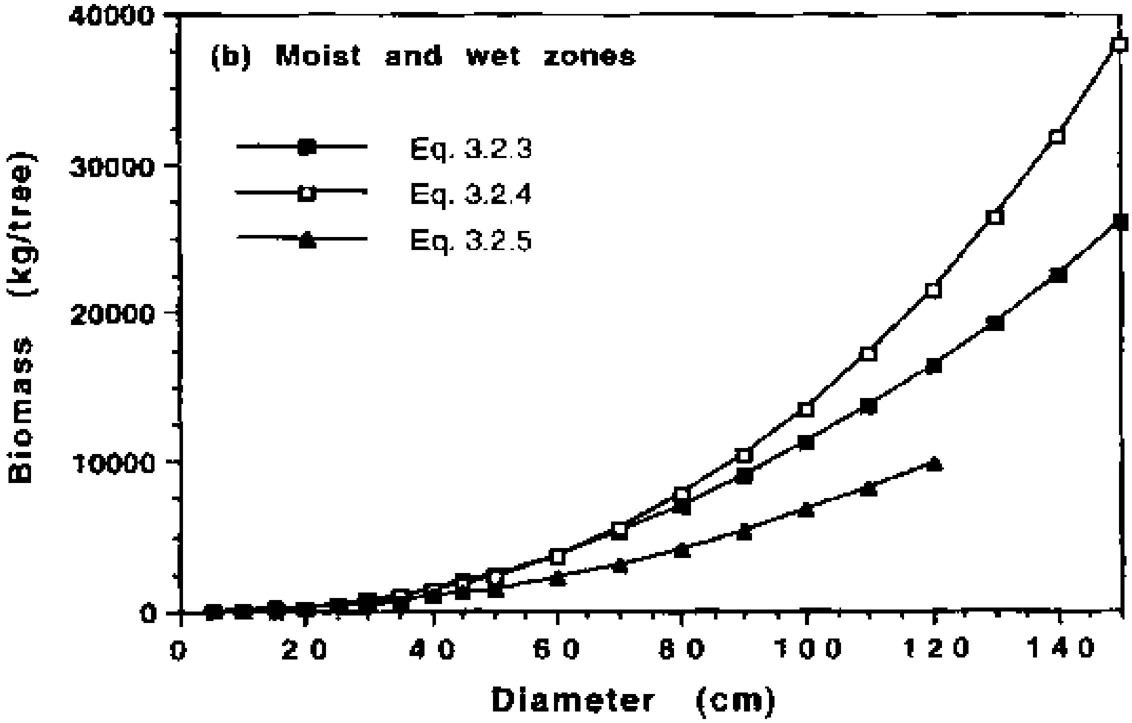
The equations are given in Section 3.2.1.

(a) All zones



(a) All zones
Eq. 3.2.1
Eq. 3.2.2
Eq. 3.2.3
Eq. 3.2.4
Eq. 3.2.5
1500
1000
500
0
Biomass (kg/tree)
0
10
20
30
40
Diameter (cm)

(b) Moist and wet zones



Biomass regression equations for estimating biomass of tropical trees. Y= biomass per tree in kg, D = dbh in cm, and BA = basal area in cm^2

Equation Number	Climatic zone	Equation	Range in dbh (cm)	Number of trees	Adjusted r^2
3.2.1	DRY [a]	Y = exp{-1.996+2.32*ln(D)}	5-40	28	0.89
3.2.2		Y =10^{-0.535+log$_{10}$ (BA)}	3-30	191	0.94
3.2.3	MOIST [b]	Y = 42.69-12.800(D)+1.242(D^2)	5-148	170	0,84
3.2.4		Y = exp{-2.134+2.530*ln(D)}			0.97
3.2.5	WET [c]	Y = 21.297-6.953(D)+0.740(D^2)	4-112	169	0.92

None of the regression equations should be used for estimating the biomass of trees whose diameter greatly exceeds the range of the original data.

(a) Eq. 3.2.1 revised from Brown et al. (1989) for dry forest in India, and Eq. 3.2.2 from Martinez-Yrizar et al. 1992 for dry forest in Mexico (original equation based on BA). For dry zones with rainfall less than 900 mm/year use equation 3.2.2 and for dry zones with rainfall > 900 mm/year use equation 3.2.1. "exp" means "e to the power of".

(b)Both equations are based on the same data base; A. J. R. Gillespie, pers. comm. based on a revision of equation in Brown et al. (1989).

© From Brown and Iverson (1992)

Analysis of the data bases implied that the trees within the dry and wet zones could be grouped together within a zone (Brown et al. 1989). Within the moist zone, the analysis indicated that different data bases were not statistically homogeneous and theoretically could not be grouped. For practical purposes, however, the moist zone was considered to be the population of interest and the different data bases were considered to be sub samples from this population. Thus a combined regression for the pooled data sets was developed (Brown et al. 1989).

Biomass regression equations for several species of pines combined into one data base was also developed.

A simple method for estimating the biomass of palms was also developed (Frangi and Lugo 1985).

Details of the: (1) evaluation of several linear, nonlinear, and transformed nonlinear regression equations, (2) the testing of the behaviour of the equations, and (3) selection of the final equations are given in Brown et al. (1989).

The behaviour of all these regression equations as a function of dbh is illustrated in Figure 1. Application of all five regression equations for smaller diameter classes shows that for a given dbh biomass is highest for trees in the moist zone (Fig. 1a; Eq. 3.2.3 and 3.2.4), followed by trees in the wet zone (Eq. 3.2.5), and trees in the dry zone (Eq. 3.2.1 and 3.2.2).

The regression equation for dry zone trees given by Eq. 3.2.1 gives higher biomass per tree for a given diameter than the regression developed for the Mexican dry zone (Eq. 3.2.2; see Fig. la). As tree diameters increase, the difference becomes larger so that by diameter 40 cm (the upper limit for the data bases) the biomass per tree based on Eq. 3.2.1 is about 1.7 times higher than that based on Eq. 3.2.2. The main reason for this trend is that the trees used for developing Eq. 3.2.1 grow in a dry deciduous forest zone of India that receives about 1200 mm/year of rainfall in contrast to the dry deciduous forests in Mexico where rainfall averaged about 700 mm/year. The result of this difference in rainfall regime is that the Mexican trees are shorter than those in India, and thus biomass for a given diameter is less. For example, height for the Mexican trees commonly ranged between 4 to 9 m, with an average height of about 7 m (Martinez-Yrizar et al. 1994), whereas those in India had heights up to about 15m (Bandhu 1973).

The tropical dry forest zone describes areas where rainfall is less than 1500 mm/year or so. For a dry zone where rainfall is similar to that for the dry deciduous zone of Mexico (about 700 to 900 mm/year or less), Eq. 3.2.2 could be used. For dry zone 'forests at the wetter end of the zone, i.e., rainfall greater than 900 mm/year, Eq. 3.2.1 should be used. However, because of the high variability of tree biomass with rainfall in the dry zone, it is recommended that local biomass regression equations be developed, or at least a few trees harvested to test how well the two equations presented here fit the local conditions.

The moist zone equations (Eq. 3.2.3 and 3.2.4) give essentially the same biomass estimates for trees with dbhs up to about 80 cm (Fig. 1b). After this diameter limit, estimates of the biomass per tree diverge markedly. However, the estimates from Eq. 3.2.4 are closer to the original data and the r^2 of the regression equation is higher than for Eq. 3.2.3 (0.97 versus 0.84)

It is not recommended that any of the regression equations be used for estimating the biomass of trees whose dbh greatly exceeds the range of the original data. However, if trees with dbh greater than 160 cm or so are encountered in an inventory, it is recommended that Eq. 3.2.3 be used for these trees as the function behaves better in these larger classes. Equation 3.2.4 is an exponential function and biomass per tree increases rapidly at large diameters. In the ideal situation where many trees with dbhs larger than 150 cm are encountered, some new field measurement of their biomass should be made . It is important that the biomass of trees with large dbh be estimated as accurately as possible because their contribution to the biomass of a forest stand is much more than their number suggests. For example, in mature moist tropical forests, the biomass in trees of dbh greater than 70 cm can account for as much as 40% of the stand's biomass density, although the number of these trees corresponds to less than 5% of all trees (Brown and Lugo 1992, Brown 1996).

The regression equation for trees in the wet zone (Eq. 3.2.5) matches the original data well and behaves well at larger diameters. As with the moist equation however, caution should be taken in using the equation much beyond the original data.

Eq.3.2.6, Y (biomass,kg) =10.0 + 6.4* total height (m);n =25, r^2 = 0.96.

(Eq.3.2.7) Palm trees; In many tropical moist and wet forests, palms are sometimes common .Estimating their biomass is difficult as few studies have been made on this topic .Futhermore, many different species exist with different forms, different proportion of their mass in leaves, and different stem densities. To estimate the biomass of palms, height measurements as well as diameter measurements will be needed. A simple way to estimate their biomass is to compute the volume of the stem as a cylinder (basal area x stem height) and then multiply this by an estimate of the density. Wood density of palms varies considerably by species and within the stem of the same

An example is given here to demonstrate the variation in the estimates from the three different methods. For a palm of 15 cm diameter, 15 m total height, and 12 m stem height, the biomass estimates are:

Method 1 –Based on volume; stem volume =0.21m^3, wood density =0.25t/m^3,stem mass =53.0 kg; assume leaves are 65% of stem, total biomass =87kg.

Method 2; Based on equation 3.2.6; total biomass =86kg.

Method 3;Based on equation 3.2.7; total biomass =87kg.

The three methods give similar values. Unless the forest is composed mostly of palms, any of these methods would be suitable for estimating biomass of palms scattered throughout moist or wet forests

However, the variation in wood density by species must be taken into consideration; higher wood density estimates need to be used for denser species. In the case of forest stands where palms are dominant, local biomass regression equations would need to be developed, or at least measurements of wood density of dominant palm species would need to be measured.

Conifer forests: Few data on the biomass of conifer trees for tropical zones exist. To develop a preliminary biomass regression equation, data on the biomass of harvested pine trees from eight literature sources, including pine forests from the south-eastern USA, India, and Puerto Rico were compiled. Several species of pine included in these sources were combined into one data base and analyzed as was done for the broadleaf forests. The resulting equation is:

Eq.3.2.8. Y(kg) =exp{-1.170+2.119*ln(D)

D =dbh,cm, range in dbh =2.52cm, number of trees =63; adjusted r^2 =0.98

For most situations where an estimate of the biomass density of pine forests is needed, Eq. 3.2.8 can be used. However, if time and resources are available, a local biomass regression equation should be developed.

Below is an example of how to use the biomass regression equations with stand tables. The stand table example is for a moist forest in Gambia. Biomass density of this forest was estimated using the moist equation, Eq. 3.2.3. Maximum diameters are at about the upper limit for this equation (about 150 cm).

Use of the biomass regression equation, an example

Diameter class (cm)						
5-20	20-40	40-60	60-90	90-120	120-150	>150
1. Number trees/ha						
794	161	25.2	12.3	3.3	1.05	0.23
2. Mid-point of class, cm						
12.5	30	50	75	105	135	155 [b]
3. Biomass of tree at mid-point of class using Eq. 3.2.3; kg						
70.5	646	2353	6563	15375	29038	41 187
4. Biomass of all trees, t/ha = (product of rows 1 and 3)/1000°						
56	104	59.3	80.7	50.8	30.5	9.5
Total aboveground biomass = sum of row 4 = 391 t/ha						

[{a}] As no additional information was available the mid-point of the diameter class was assumed to represent the class; as the classes are wide this could overestimate the biomass density estimate.

[{b}] Assumed to be diameter of largest class; choice of this upper limit when no additional data are present is problematic.

[{c}] To convert kg to t.

Although the approach presented here has emphasized the use of regression equations with stand tables, the regression equations can also be used with individual tree measurements from stands. Using individual tree measurements overcomes the problem of choosing the diameter of the class.

Several problems exist with this method, namely: (1) the small number of large diameter trees used in the regression equations (e.g., for the moist equation, the largest dbh was 148 cm, with only five trees >100 cm diameter), (2) the open-ended nature of the large diameter classes of the stand tables, (3) wide and often uneven-width diameter classes, (4) selection of the appropriate average diameter to represent a diameter class, and (5) missing smaller diameter classes (i.e., incomplete stand tables to minimum diameter of 10 cm).

To overcome the potential problem of the lack of large trees (problem 1), equations were selected that were expected to behave reasonably up to 150 cm or so or upon extrapolation somewhat beyond this limit (Brown et al. 1989). Rarely are stand tables encountered that contain trees much larger than the maximum dbh used in the regression.

The problem with open-ended large diameter classes is knowing what diameter to assign to that class. Sometimes additional information is included that educated estimates can be made, but this is often not the case. Clearly, further improvements in reporting the distribution of the largest diameter trees in stand tables would improve the reliability of the biomass density estimates as it is often these large trees that account for significant proportions of the total biomass density (Brown and Lugo 1992, Brown 1995). In the above example, the approximately 1.3 trees greater than 120 cm constitute about 70% of the biomass represented by the 794 trees in the smallest class.

Many inventories often report stand tables with wide and/or uneven-width classes. The most unbiased biomass density estimate is obtained when diameter classes are small, about 10 cm wide or smaller, and are even-width for the whole stand table. This problem is illustrated by the following example for a moist forest where in Example A the classes are 10 cm wide and in Example B two classes are combined to make them 20 cm wide.

Example A

Diameter class (cm)											
10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	>120
Number of stems/ha											
183	80	35.1	11.8	4.7	2.3	1.5	0.9	0.5	0.4	0.2	0.5
Biomass/tree (kg) at mid-point of class(Eq. 3.2.3)											
112	407	954	1 802	2995	4570	6563	9008	11936	15375	19354	23900
Biomass of trees (product of rows 1 and 2), t/ha											
20.5	32.6	33.5	21.3	14.1	10.5	9.8	8.1	6.0	6.2	3.9	12.0
Total biomass density =178 t/ha											

Example B

Diameter class (cm)					
10-29	30-49	50-69	70-89	90-109	>110
1. Number of stems/ha					
263	46.9	7.0	2.4	0.9	0.7
2. Biomass/tree (kg) at mid-point of class(Eq. 3.2.3)					
232	1 338	3732	7727	13590	21 555
3. Biomass of trees (product of rows 1 and 2), t/ha					
60.9	62.7	26.1	18.5	12.2	15.1
Total biomass density =196 t/ha					

The biomass density in Example B, based on the 20 cm wide classes, is about 10% higher than that in Example A, based on the 10 cm wide class. In general, wider classes will overestimate the biomass density. However, regular estimation of biomass density as part of inventory analysis or accessibility to the field data should not encounter these problems because original inventory data generally includes details down to individual trees. Estimating the biomass of individual trees in inventory plots directly would overcome problems (2) to (4) given above. Foresters have wide experience in these type of calculations as they are basically no different from estimating volumes from volume equations.

To overcome the problem of incomplete stand tables, an approach has been developed for estimating the number of trees in smaller diameter classes based on number of trees in larger classes (Gillespie et al. 1992). It is recommended that the method described here be used for estimating the number of trees in one to two small classes only to complete a stand table to a minimum diameter of 10 cm. It is also emphasized that this method should only be used when no other data for biomass estimation are available.

The method is based on the concept that uneven-aged forest stands have a characteristic exponential or "inverse J-shaped" diameter distribution. These distribution have a large number of trees in the small classes and gradually decreasing numbers in medium to large classes. Full details of the theory behind the approach and of the different methods tested are given in Gillespie et al. (1992).

The best method was the one that estimated the number of trees in the missing smallest class as the ratio of the number of trees in dbh class 1 (the smallest reported class) to the number in dbh class 2 (the next smallest class) times the number in dbh class 1. This method is demonstrated in the following example:

1 Assume that: the minimum diameter class is 20-30 cm and we wish to estimate the number of trees in the 10-20 cm class.

2 The number of trees in the 20-30 cm class equals 80, and the number in the 30-40 cm class equals 35.

3 The estimated number of trees in the 10-20 cm class is the number in the 20-30 cm class x (number in 20-30/number in 30-40); this equals 80 x (80/35) =183.

To use this approach, diameter classes must be of uniform width, preferably no wider than 10-15 cm, and should not be used for estimating numbers of trees in more than two "missing' classes.

The regression equations reported above can be applied to inventories of individual trees planted in lines, as living fence posts, for dune stabilization, for fuel wood, etc. Biomass estimates for individual trees are particularly useful in drier regions where the trees are grown for all the aforementioned products and services. However, as discussed above, the regression equations for dry zone trees are based on a small data base. Furthermore, trees grown in lines or in more open conditions generally display different branching patterns and are likely to have more biomass for a given diameter than a similar diameter tree grown in a stand. Although the above regression equations could be used where no other data exist for rough approximations, new regression equations need to be developed for trees growing in open conditions.

Estimating the biomass density of plantations can be done using techniques similar to those for native forests as described above. Inventoried volume can be converted to aboveground biomass density using Eq. 3.2.1 outlined in Section 3.2. However, the equation for BEFs (Eq. 3.2.4) would not necessarily work in the case of plantations of broadleaf species because tree form is likely to be different in managed forests and definitions of inventoried volumes are also likely to be different. It is recommended that BEFs be locally derived. The biomass regression equations for broadleaf species (Eq. 3.2.1-3.2.5) could also be used for plantations, but once again caution should be taken with their use. Direct biomass measurements of representative plantation trees should be made to check the validity of the regression equations, or even better local biomass regression equations should be developed..

For plantations of conifer species, the average BEF of 1.3 given for pine forests in Section 3.2.3 could be used if measured volume was based on the total stem.

In the case where diameters of individual plantation trees or diameter distributions are given, Eq. 3.2.8 could be used, taking the same precautions as for broadleaf species. Kadeba (1989) developed biomass regression equations for plantations of Pinus caribaea trees growing in the savanna zone of Nigeria with annual rainfall ranging from 1250 to 1800 mm/year. However, the data base spanned a small diameter range, about 15-25 cm, and each equation was based on 12 trees only.

In situations where lack of resources prevent the development of local biomass regression equations for plantations, use of any or the above approaches would give a reasonably good estimate of the aboveground biomass density.

This research work does not include methods or approaches for making biomass density estimates for (1) understorey (including e.g., bamboo or rattan), (2) belowground woody biomass such as fine and coarse roots, (3) forest floor fine litter (e.g., dead leaves, twigs, fruits, etc.), nor (4) lying and standing dead wood. Most efforts on biomass estimation to date have generally focused on the aboveground tree component because it accounts for the greatest fraction of total biomass density and the methods are straightforward and generally do not pose too many logistical problems. Commonly reported ranges of biomass density estimates for these other components are given below, although they must be used with caution as the data base on which they are built is limited.

Summary of estimates of biomass density of other forest components, expressed as a percent of aboveground biomass in trees

Component	Percent of aboveground! biomass of mature forest!
Understorey	□ 3
Belowground (roots)	4-230
Fine litter (dead plant material)	□ 5
Dead wood	5-40

The amount of biomass in understorey shrubs, vines, and herbaceous plants can be variable but is generally about 3 percent or less of the aboveground biomass of more mature forests (Jordan and Uhl 1978, Tanner 1980, Hegarty 1989, Lugo 1992).

However, in secondary forests or disturbed forest, this fraction could be higher (e.g., up to 30%; Brown and Lugo 1990, Lugo 1992) depending on age of the secondary forest and openness of canopy. Palms are common in many tropical moist forests and they are also often ignored in forest inventories. Their contribution to total biomass density can be very variable, from nearly 100 percent to less than a few percent.

The biomass of roots varies considerably among tropical forests depending mainly upon climate and soil characteristics (Brown and Lugo 1982, Sanford and Cuevas 1996). Root biomass is often expressed in relation to aboveground biomass, such as a root-to-shoot ratio (R/S ratio). A recent review of the literature gives the R/S ratios (from Sanford and Cuevas 1996) shown in the table on the next section.

These estimates of R/S are based on only a few studies (about 30) and not all of them are consistent with respect to depth of sampling and nor whether coarse roots were included. It seems clear from this research work that more studies of root biomass and their relationship with other factors such as aboveground biomass, climate and soil, are needed.

The amount of dead plant material in a forest, or detritus, is composed of fine litter on the forest floor, (leaves, fruits, flowers, twigs, bark fragments, branches less than 10 cm diameter, etc.), standing dead trees and snags, and lying dead wood greater than 10 cm diameter. The biomass density of fine litter ranges from about 2 to 16 t/ha (average of 6 t/ha or less than 5% of aboveground biomass), with higher values generally in moist environments although no clear trend is apparent in the data base (Brown and Lugo 1982). The amount of fine litter on the forest floor represents the balance between inputs from litterfall and outputs from decomposition, both of which vary widely across the tropics.

The amount of dead wood in tropical forests is poorly quantified but extremely variable. It is potentially a large pool of organic matter, perhaps accounting for an amount equivalent to less than 10 percent to more than 40 percent of the aboveground biomass of a forest depending upon forest age and climatic regime (Saldarriaga et al. 1986, Uhl et al. 1988, Uhl and Kauffman 1990; Delaney et al. 1997). Lack of data on this significant forest component obviously can lead to underestimates of the total amount of biomass in a forest.

It is clear from the research work that ignoring these other forest components can seriously underestimate the total biomass of a forest by an amount equivalent to about 50 percent or more of aboveground biomass. Although this is not the focus of the research work, it is apparent that logistically and economically feasible methods and approaches must be developed to estimate this significant quantity of biomass and its range of uncertainty, especially for improving estimates of terrestrial sources and sinks of carbon and biogeochemical cycles of other elements.

Forest type	Range of R/S	Average R/S
Moist forest growing on spodosols	0.7 - 2.3	1.5
Lowland moist forest	0.04 - 0.33	0.12
Montane moist forests	0.11 - 0.33	0.22
Deciduousforests (e.g., tropical dry and seasonal forests)	0.23 - 0.85	0.47

Topography and forest cover are two major interconnecting factors influencing the finer details of vegetation variation (e.g., structure, biomass) within a forest (Whitmore, 1998).

The 8 sample plots were created using a hybrid reconnaissance and stratified random sampling strategy. The stratification of the landscape into sampling area and sampling units will, therefore, be a result of both environmental characterization and imagery interpretation. The majority of the plots were located along road corridors to minimize accessibility concerns.

Dahl Environmental Services, LLC applied standard forest mensuration practices during the field cruise to determine volumes and cubic measures for forest trees and biomass. All trees were measured for diameter and height. Diameter estimates were obtained using a diameter tape or Biltmore stick. Diameters were taken at root collar (DRC, just above the swelling at the top of the root collar) for piñon pine and common junipers. Diameters were taken at breast height (DBH, 4 ½ feet above the ground) for all other conifers. Total tree heights were measured using either a clinometer or Biltmore stick. Ocular estimates were made to determine total tree heights for trees generally under 20 feet. Ocular estimates were re-calibrated and validated daily using the clinometer.

The strata were inventoried using 1/20th acre fixed radius plots (26.4 feet diameter). Plot locations were predetermined by NCDC and placed on maps.

DES utilized GPS units to locate plot centres.

A stake was placed at plot centre and a 26.4 foot string was straightened, from the stake, and rotated clockwise from north to determine the plot boundary. All trees within the plot circle were tallied. Trees were recorded by number, species, diameter and total height. All recorded field data was later entered into cruising software programs, either BIOCRUZ or PJCRUZ, to determine tree volumes and cubic measures.

3.3.3 Remote Sensing and GIS Data Collection

Remotely sensed data have long promised to facilitate the mapping and monitoring of vegetation at a landscape scale (Cihlar, 2000). This goal is becoming realistic with the advent of a new generation of sensors which offer significant improvements in the spatial, spectral, and radiometric properties as well as in optics and signal-to-noise ratio of data. High spatial resolution allows for location while high spectral resolution allows identification of features. Recent work with high resolution images have demonstrated the possibility of extracting the location of individual tree crowns from 2 foot multispectral data to produce image maps representing stem densities and crown cover densities.

Conventional methods of vegetation analysis involve identifying species, life-forms, structure (vertical stratification), abundance, basal area, volume, and biomass (Fuller et al. 1998, Garrity and Khan 1994) and require a large number of samples. For large areas, this can be time consuming and require a significant budget for conducting sufficient field surveys. Yet, conventional methods do not have the advantage of the spectral characteristics of remotely sensed data for extrapolation of themes mapped at one location to other similar areas elsewhere. Further, the data gathered through conventional techniques are not inherently spatial, but are brought to spatial mode through geospatial statistics that often fail to capture much of the spatial variability (Isaaks and Srivastava 1989).

With the launch of the QuickBird satellite and subsequent availability of QuickBird imagery in high-resolution, multispectral 11-bit data, remote sensing was ushered into a new era. Other new generation sensors such as Landsat-7 ETM+ have slightly coarser spatial resolution (30 meter) but have more spectral bands than QuickBird. The QuickBird characteristics provide an opportunity for capturing quantitative parameters of floristic changes across small topographic gradients at a very fine spatial resolution to capture spectra from individual units such as a tree crown. The ETM+ captures data in wider number of spectral bands that include the mid infrared portion of the spectrum.

This enables possibilities of better spectral relationships with characteristics such as forest cover type. Thereby, an opportunity now exists for the development of more refined vegetation mapping of forest landscapes taking single tree species or homogeneous monocultures of few trees as a unit rather than using heterogeneous landscape units as themes of vegetation, land cover, or land use.

There is a distinct difference in total biomass versus available biomass. There are several constraints that decrease the number of acres available for biomass. These constraints include, but are not limited to:

1) Inventoried Roadless Areas, where road construction and reconstruction is prohibited

2) Special Designated Areas

NWA = National Wilderness Area

NPA = National Primitive Area

NSRA = National Scenic Research Area

NSA = National Scenic Area

NWSR = National Wild and Scenic River

NRA = National Recreation Area

NGRWP = National Game Refuge and Wildlife

NVM = National Volcanic Monument

NHA = National Historic Area

WSA = Wilderness Study Area

RNA = Research Natural Area

OCD = Other Congressionally Designated Areas

3) Slope Exclusion Zones .Defined as areas of greater than 30% slope

These constraints have been modelled in a GIS environment for use in this research .Because of the size of the study area, data available from the USFS Forest Inventory Analysis (FIA) Data Retrieval System describing potentially harvestable forests are not spatially specific and are only accurate on a larger scale than is required for evaluating biomass supply for a power plant.

Even if the data were accurate at this scale, there would still be little information as to where the biomass was located.

This research was aimed at developing a system to correlate field-based plot biomass estimates with forest biotic parameters obtained through multiple-resolution remote sensing techniques to provide a more robust methodology to estimate biomass. First, plot data was entered into the PJCRUZ or BIOCRUZ spreadsheets, as appropriate, to determine cubic volume which is then converted to dry weight.

3.4 QUANTITATIVE DATA.

A variety of approaches have been developed to estimate aboveground biomass of forests and woodlands. These methods differ in procedure, complexity and time requirement depending on the specific aim of estimation operation. The approaches can be divided into two main categories; being non-destructive and destructive methods.

.3.4.1 Non-destructive methods of estimating biomass .

Non-destructive method is when biomass of a tree is estimated without felling the tree itself (Montes et al., 2000). This method is mainly applied when the species of interest are rare or protected and can not be destructively sampled to determine allometric relationship (Brown, 1997; Montes et al., 2000; Stewart et al., 1992; Vann et al., 1998). Literature shows that a number of methods of estimating aboveground biomass without necessarily destroying the tree are available under this category. One such method is whereby a tree is climbed, and successive measurements on stems and branches are taken along with limited sampling of branches which are then weighed (Vann et al., 1998). Stem weight estimates are derived from wood density measurements from cores and sections from dead stems (Vann et al., 1998). The advantage with this method is that the tree is not entirely destroyed but an element of destruction is there. Two major disadvantages with this method are that; firstly, the reliability of the method is not easy to validate since felling is not applied. Secondly, the method can be time consuming and labour intensive as well as cumbersome.

The second and last method considered in this research work under this category is the model stem method proposed by Adhikari (2005) adopted and improved from the non-destructive method developed by Montes et al., (2000). The original method (Montes et al., 2000) was developed for Junipe rusthurifera, a protected tree species, to estimate its volume based on the dimensions of the tree photograph. The method uses grid cells which are superimposed on a photograph rather than weighing the tree itself. Since it is not possible to measure the weight of a tree in the photograph, different components can be estimated from the photograph using approximations of geometric solids and corresponding diameter measurements. Using this method, biomass can be estimated from the volume by using the density of the tree component which is sampled from the tree. Adhikari (2005) concluded that the model stem method is reliable based on the tests done on it. The method does not require heavy machinery, it only requires a camera. However, like the first method, this method also has an element of destructiveness, it becomes destructive the moment a factor of density is included for calculating biomass because that factor was developed using a destructive method.

3.4.2. Destructive methods of estimating biomass

.Destructive method is when biomass is measured directly by felling the trees (Stewart et al). It is also destructive when biomass is obtained indirectly through sub-sample. A number of methods are available through destructive means. One such method is complete harvesting method. It involves total harvesting of randomly selected plots or individual trees within the plot (Stewart et al., 1992; Vann et al., 1998). This method involves cutting and weighing or cutting, drying and weighing of the whole tree or its components. The method is straight forward and it estimates fresh biomass on the field. It can estimate dry biomass but the procedure is not practical as the whole tree has to be oven dried. Stewart et al., (1992) identified two major limitations regarding this method. Firstly the process is destructive hence the chance of observing growth over a longer period is lost. Secondly, the method is prohibitively time consuming hence costly. The second method is the tree sub-sampling method. This method does not require cutting and weighing or cutting drying and weighing of the whole tree. It estimates aboveground woody biomass from a small, randomly selected sample collected from the tree and weighing or drying and weighing the sample to obtain an unbiased estimate of volume, fresh and dry weight biomass. It works equally well for trees and shrubs. It requires in-the-field data processing. Through past studies (de Gier, 1989; de Gier, 1995; de Gier, 1999; de Gier, 2003) concluded that this method is competent in terms of time and cost as compared to complete tree harvest method for example, a twice executed sub-sampling procedure per tree requires between 10 minutes and two hours, with and average of 30 minutes (depending on the tree size) for a crew of two. It does not require heavy instruments; in fact all instruments can be carried by hand. The disadvantage with the method is that the procedure itself is somewhat complicated. However, de Gier (1989) minimized this problem by writing a program for use with a hand held computer. The sub-sampling method estimates are then used to construct biomass equations.

Most researchers (Brown, 1997; Lott et al., 2000; Sah et al., 2004; Stewart et al., 1992; Tietema, 1993; Vann et al., 1998) perceive this method as non-destructive. The method is destructive as far as constructing those equations is concerned. Moreover, when biomass equations are used, it is always necessary that they are validated (Chave et al., 2004). Hence validation entails tree felling of a sufficient number (>25) of representative trees (de Gier, 1999) while Chave et al., (2004) suggests at least 50 trees. Biomass equations are ideal for estimating biomass once they are available (Brown, 1997). But developing these equations for different forests and vegetation types require destructive sampling.

Usually a sample of trees are felled and used to develop regression functions from which biomass can be predicted using easily and non-destructively measurable variables such as the tree height and stem diameter (Stewart et al., 1992).

The problem associated with allometric equations is the error propagation for biomass estimation. For example, measurement errors in stem diameter, tree height or crown diameters all result in error in estimating aboveground biomass through propagation (Chave et al., 2004). For the construction of the allometric equations, the form of the linear and non linear models has been built (Fox. J, 1997; Stewart et al., 1992; Vann et al., 1998; Zianis and Mencuccini, 2004) but the most commonly used mathematical model in biomass studies is using a regression on the logarithmic transformed variables (Chave et al., 2004; Zianis and Mencuccini, 2004). For example, Tietema (1993) developed regression curves of 14 tree species in Botswana using power functions after logarithmic transformation. The tree species involved were Acaci aerioloba, Acacia erubescens, Acacia karroo, Acacia luederitzii, Acacia mallifera, Acacia tortilis, Boscia albitrunca, Colophospermum mopane, Combretum apiculatum, Combretum molle, Croton gratissimus, Dycrostachys cinerea, Terminalia sericea,and Ziziphus mucronata. Similarly, Brown (1997) developed biomass equations for both dry and wet regions based on the same logarithmic transformation approach. Harrel et al., (1997) found that the use of logarithmic transformation mask the true levels of ambiguity. Chave et al., (2004) contends that the residuals represent the departure from a perfect allometry, and are normally distributed. In addition, the standard deviation of these residuals represents the uncertainty in the biomass estimation due to the allometry itself. Sah et al., (2004) also concluded that logarithmic models generally give under predictions and as such a correction factor has to be applied in the back transformation of the data. Sprugel (1983) cited by Cleemput et al., (2004) found that equations developed with transformed data have the potential for bias. De Gier (1999) found that third degree polynomials with backward elimination, combined with weighing to obtain constant (homoscedastic) residual variance are much better and not biased as compared to power functions. For this reason, logarithmic transformations and power functions will not be used in the development of biomass equations in this research..

After an intensive literature review about woody biomass estimation methods, a number of approaches described above were found, but it was difficult to out rightly select a method to be applied in this research. Therefore, a criterion was designed for the selection of the method to be used in this research. The method must satisfy the following requirements;

It must be competent in terms of time and cost associated with data collection.

It must require less manpower (maximum of three people) without necessarily compromising the reliability of the field data collected.

• It must not require heavy instruments as this may have implications on the financial resources.

• It must be applicable in Gambia for example, it should work equally well for trees and shrubs in the savanna type of ecosystem.

After critically assessing the methods through the set criterion, the model stem method proposed by Adhikari (2005) originally developed by Montes et al., (2000) and the sub-sampling method by de Gier (1989) were both selected as they met all the requirements. The methods would be compared in terms of reliability of the estimated biomass and time requirements in the field and the best method selected and used further in this research. Complete harvesting methods would be used to validate the two methods.

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3.4.3 Relating biomass to image data (Remote sensing) .

As already alluded, the traditional way of collecting forest data is through manual, field based observation. This approach has the benefit of generating highly accurate measurements, but due to its labour intensive nature, high cost associated with the length of time spent in the field, and often constrained by lack of access (Couteron et al., 2001; de Gier, 1989; de Gier, 1995; Hansen et al., 2002; Harrell et al., 1997; Kasischke et al., 1997), this approach is generally not practical for anything other than local scale studies (Aplin, 2003). However, the implications of forest analysis extend well beyond the local scale, and there is considerable need for forest investigation at wider spatial scales. As a result, the technique of remote sensing has become common in forest investigation providing the only realistic and cost effective way of acquiring data over larger areas (Aplin, 2003; Couteron et al., 2001; Gemmell and McDonald, 2000). The technique has gained considerable importance in vegetation mapping and monitoring over the last two decades (SADC and ETC-Foundation, 1987). It has also been used directly in ecological studies to; investigate landscape patterns, to exploit correlations among physical, chemical and biotic parameters and to extrapolate known relationships over wider geographic areas or longer time periods (Kasischke et al., 1997).

However, a robust method for extracting forest characteristics from remotely sensed data has yet to be fully developed (Gemmell and McDonald, 2000). Remotely sensed data is a readily available and accessible (though in some cases it can be costly) global resource that provides wider variety and greater quantity of information relative to traditional mapping data (Repaka et al., 2002). Preferably, woody biomass resource assessment needs to be undertaken using remotely sensed data combined with ground data (SADC and ETC-Foundation, 1987). The ground data would be used for validating the remote sensing data. Highly accurate maps can be derived from satellite image data when combined with ground data (ITC, 2004). One major reason of using remote sensing imagery to estimate woody biomass is that it complements part of the field work which is practically more expensive, by less expensive image analysis (de Gier, 1989). This will of course depend among other things on the cost of acquiring the satellite imagery. Remote sensing provides ancillary benefits such as information about adjacent areas, whereas ground based methods generally only provide information about the specific area of interest. Furthermore, remote sensing provides data at a synoptic scale from a single data-take for resource assessment over large areas (ITC, 2004; SADC and ETC-Foundation, 1987). Moreover, repeat imagery for any scene can be acquired and there is consistency across larger areas, making it suitable for national and international monitoring. Whilst remote sensing has become a key technique in forest investigation, there are limitations with regard to the spatial detail of these data. Narayan (1999), reports that remote sensing by satellite became a reality in 1972 with the launching of the first earth resources technology satellite (ERTS) by the US. The ground resolution of Landsat 1 then was 80 m. As time went by, better quality and better quantity of satellite remotely sensed data particularly in terms of spatial and temporal resolutions started arriving (Narayan, 1999). Today, Landsat ETM operates in three spatial resolutions; 15 m (Panchromatic), 30 m (bands 1 -5,7) and 60 m (band 6) (ITC, 2004).

Recently, more fine spatial resolution satellite sensors have emerged providing imagery with a level of detail that may be sufficient for meaningful and accurate ecological investigation (de Leeuw et al., 2002). Satellite imagery with spatial resolution of 1 m (panchromatic) and 4 m (multi-spectral) is available from satellites such as 'IKONOS' and 'QuickBird' systems (ITC, 2004).

Fine spatial resolution satellite sensor imagery have been used for a range of ecological applications particularly forest analysis and some of the earliest published examples of IKONOS data exploitation relate to biomass (Aplin, 2003).

IKONOS operates in the following spectral bands; 0.45-0.52m (1), 0.52-0.60m (2), 0.63-0.69m (3), 0.76-0.90m (4) and 0.45-0.90m - Panchromatic (Hansen et al., 2002; ITC, 2004). Its capabilities include capturing a 3.2 m multi-spectral, and 0.82 m panchromatic resolution at nadir with off nadir capabilities of 1 m (panchromatic) and 4 m (bands 1-4) (Satellite Imaging Corporation, 2005). Its applications include both urban and rural mapping of natural resources and of natural disasters, agriculture and forestry analysis, mining, engineering, construction, and change detection.

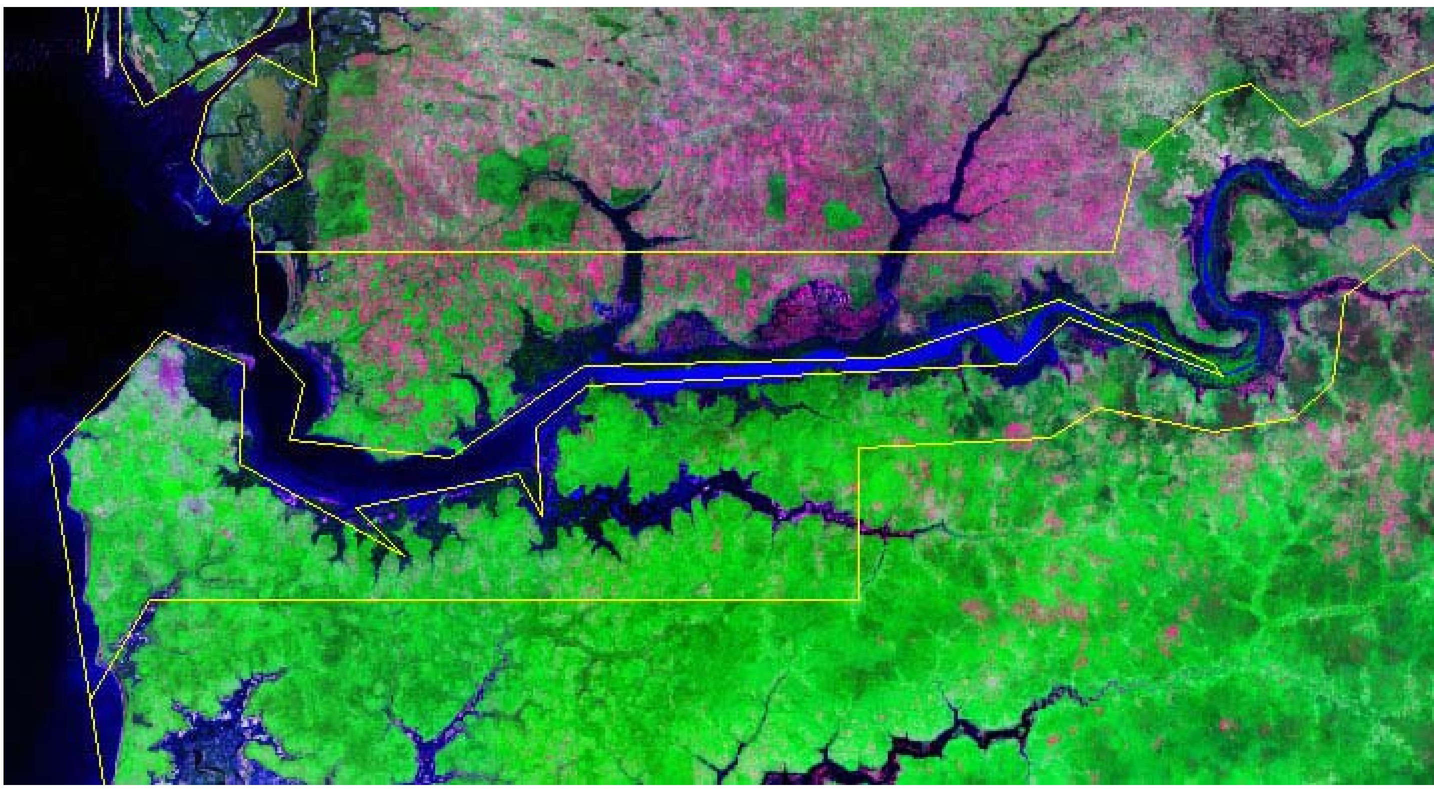
The advantage of IKONOS as a fine spatial resolution satellite over Landsat ETM with its spatial resolution of 30 m (coarse) is that as spatial resolution increases, the accuracy with which objects are identified, assessed and characterised also increases (Aplin, 2003). Hence, with IKONOS imagery, improved quality and content is higher than in most satellites available today (Satellite Imaging Corporation, 2005). It is able to discriminate and map forest resource features. IKONOS imagery provides valuable source of detailed information for environmental monitoring and development planning (Satellite Imaging Corporation, 2005). However, one major disadvantage of IKONOS imagery is that these data quickly become uneconomic for large area studies. This uneconomic characteristic has led researchers like Morisette et al., (2003), to exploit the possibility of using IKONOS imagery for Moderate Resolution Imaging Spectroradiometer (MODIS) validation elsewhere in Africa including Gambia. The other shortcoming of IKONOS satellite system is that it operates in the visible and near-infra red (NIR) regions of the electromagnetic spectrum, yet visible – IR data do not directly sense any tree or forest stand characteristics that can be directly correlated with changes in biomass (Harrell et al., 1997).

Remote sensing systems operate in several regions of the electromagnetic (EM) spectrum. The optical part of the EM spectrum refers to the part in which optical phenomena of reflection and refraction can be used to focus the radiation (ITC, 2004). It extends from X-rays to far infra-red. The longer wavelengths used for remote sensing are in the thermal infra-red and microwave regions (ITC, 2004). The visible region of the EM spectrum is the only portion with the concept of colour. Blue green and red are known as the primary colours or wavelengths of the visible spectrum.

The earth's surface is made up of different materials both natural and man made.

For each material, specific reflectance curves can be established. The curves show the fraction of incident radiation that is reflected as a function of wavelength (ITC, 2004). For vegetation ,the reflectance characteristics depend on the properties of the leafs such as orientation and structure of the leafs i.e. leaf pigmentation, leaf thickness and composition (cell structure), and on the amount of water in the leaf tissue (ITC, 2004). For example, in the visible bands of the spectrum, the reflection from the blue and red light is relatively low since in this portions light is absorbed by the plants (mainly chlorophyll) for photosynthesis and vegetation reflects somewhat more green light, whereas in the NIR bands reflectance is highest (ITC, 2004). But the amount depends on leaf growth and cell structure.

SATELLITE IMAGERY OF THE GAMBIA.

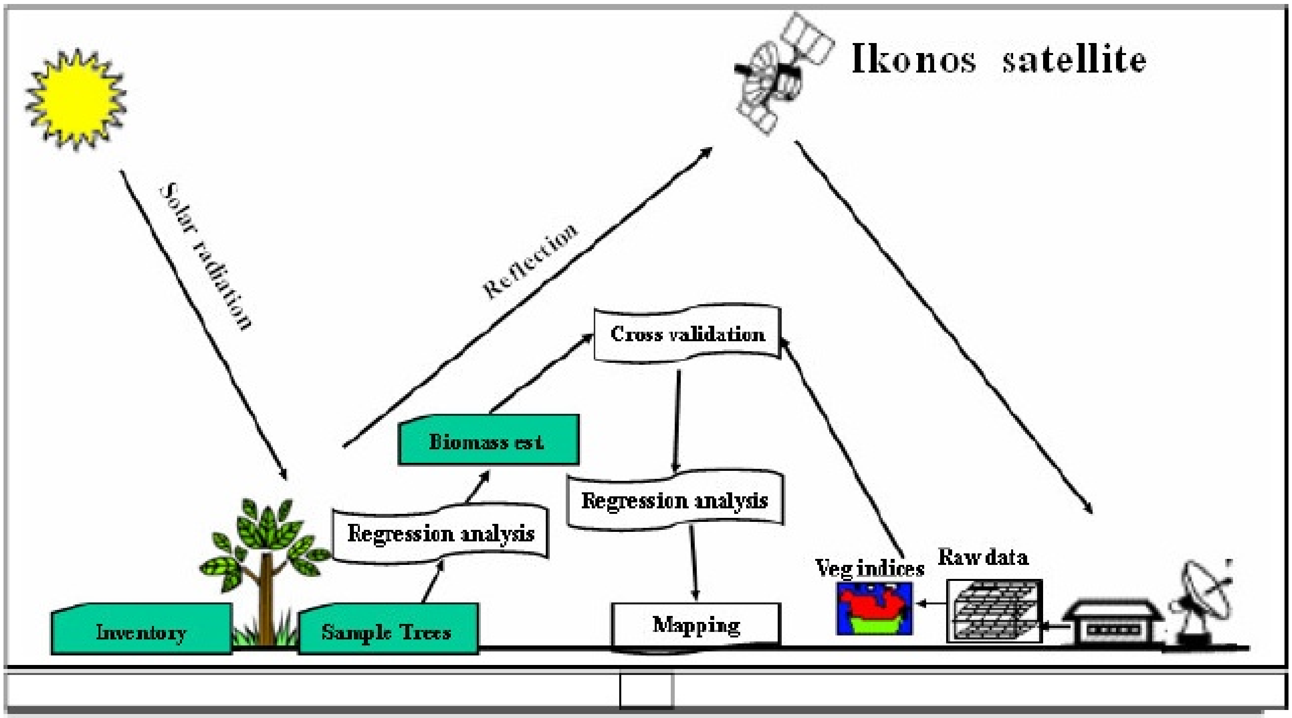


3.4.4 Spectral Vegetation Indices (VI's)

As already alluded to, forest investigation using only ground data collection is labour intensive and time consuming. Remote sensing technique can be used to complement ground data collection exercise with carefully selected sampling sites. Recently, there has been considerable interest in using remote sensing to relate biophysical parameters to different spectral vegetation indices (VI's) derived from satellite imagery.

VI's have been very widely applied to multi-spectral data (Gemmell and McDonald, 2000). They are computed as a carefully chosen combination of reflection coefficients in various wavelengths (Casanova et al., 1998) of the electromagnetic spectrum. The most popular ones using the red and near infrared wavelengths emphasize the difference between the strong absorption of red electromagnetic radiation and the strong scatter of near infrared radiation (Lu et al., 2004). The Normalized Difference Vegetation Index (NDVI) is one of the most commonly used vegetation. indices in many applications relevant to the analysis of the biophysical parameters. NVDI is calculated as the normalized ratio between channel 3 (red) and channel 4 (near-infrared) data sensed by IKONOS. The main advantages of using NDVI for monitoring vegetation are: (i) the simplicity of the calculation; (ii) and the high degree of correlation between NDVI and a variety of vegetation parameters (de Gier, 1995; Hess et al., 1995). The main advantage of vegetation indices over individual wavebands is that they can be designed to minimize the effects of disturbing factors including soil brightness (Gemmell and McDonald, 2000) on the relationship between reflectance and vegetation characteristics of interest such as canopy cover (Casanova et al., 1998). Undesirable factors are differences in soil background or atmospheric conditions (Casanova et al 1998). For example, Gambia as a semi arid country is characterized by various types of savanna vegetation. The sand covered area (where the study area is located) supports green vegetation consisting of shrub savanna, scattered tree savannah, semi-arid shrub savanna and grass savanna (Ringrose et al., 1999; Selaolo, 1998). Based on this background, the spectral reflectance is expected to be greatly influenced by soil patches on the ground. Thenkabail (2004) found that NDVI calculated from IKONOS imagery is relatively sensitive to soil background effects due to the small pixel size of IKONOS compared with Landsat ETM+ NDVI. Hence NDVI may not give accurate results. To find an index that is independent of soil influence, Wiegand and Richardson (1987) as cited by Casanova (1998), introduced the Perpendicular Vegetation Index (PVI) for which soil reflectance has to be known.

The other vegetation index which could take care of soil background effect is the Soil Adjusted Vegetation Index (SAVI). It is a transformation technique that minimizes soil brightness influences from spectral vegetation indices involving red and near-infrared wavelengths. Enhanced Vegetation Index (EVI) is also going to be exploited in this research. Like the SAVI, EVI minimizes the soil background effect and enhances the capability of the vegetation index to respond to vegetation abundance. However, difficulties may arise in that, by minimizing the sensitivity of an index to one extraneous factor, the index may then become insensitive to the factor of interest, or sensitive to other extraneous factors (Gemmell and McDonald, 2000).



Kasischke (1997) noted that studies have demonstrated that approaches using optical remotely sensed data are not appropriate for most terrestrial ecosystems because there is saturation effect at very low levels of biomass. Saturation is when a dependent variable (e.g. biomass) levels off and ceases to increase with increase in the independent variable (e.g. vegetation index). However, in Gambia not much has been done with respect to the relation between VI's and woody biomass. It is therefore assumed that those problems cited by other researchers will not be experienced since the study area is different from theirs.

Quantitative assessment of aboveground biomass in terms of volume, fresh and or dry weight per unit area is a useful way of providing estimates of various components that can be harvested. Though it is time consuming and labour intensive [couteron et al;;2001, de Gier, 1989,1995;Hansen et al;2002, Harrell et al;1997, Kasischke et al ;sah et al;2004] hence costly. Assessment of aboveground biomass in terms of volume and or weight is more relevant for forest and woodlands in the Gambia.

This is because the major products derived from these forests and woodland is related to the use of wood .Wood resources in the Gambia are declining especially near settlements because of fuel wood harvesting [van Heist and kooiman,1992].

The Government of Gambia statistics [2001] indicates that fuel wood is the leading source of energy with 54%.Therefore, there is need for interventions to reverse this trend. But due to limited financial and manpower resources, implementation for forestry programmes are seriously affected [kgathi, 1997, Tietema, 1993, van Heist and Kooiman, 1992].consequently, informed decision making which is necessary for the effective use of the limited available resources is not done. This decision making process requires information on the magnitude to which the standing woody biomass can meet local demands. Unfortunately for Gambia, up to date information on aboveground woody biomass resources is lacking. Most of the studies conducted are socio-economic in nature hence concentrating on the demand rather than the supply of woody biomass resources. Therefore, information on supply and demand of fuel wood resource at national level is insufficient, unreliable and also fragmented (Government of Gambia, 2001; Ringrose et al., 1988; Tietema, 1993). To address the woody biomass estimation problem in Gambia in a way that will lead to the alleviation of biomass scarcity and its related problems of irreversible environmental degradation, through informed decision making, there is need for sufficient and accurate data on the various aspects of this resource to be collected.

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3.4.5 Study area selection

For a particular study area to be considered, the following criteria had to be met;

- Cutting of trees for research purposes must be permissible.
- The area should be accessible by foot or by vehicle to afar plots.
- Satellite imagery and maps must be available.
- Support staff should be available.
- The area should be representative of typical Gambia vegetation.

The research was undertaken in the Western Region of The Gambia where the above mentioned criteria were met.

Satellite imagery for the researched area was available. The study area was relatively open and accessing afar sample plots by car was possible and this was an advantage on my side given the limited duration of field data collection. Moreover, the study area is located within Abuko Nature Reserve 134 Western Division Tanji River (Karinti) Bird Reserve 612 Western Division Bao-Bolong Wetland Reserve 22,000 North Bank Division Kiang West National Park 11,526 Lower River Division River Gambia National Park 589 Central River Division Nuimi National Park 4,940 North Bank Division Tanbi Wetland Complex 6,000 Western /Kombo St. Mary's Divisions, which is a collaboration effort between ITC and the department of Geological Survey of Gambia (DGS). Therefore the relevant data was available and logistics in terms of transportation, camping facilities and support staff were arranged without difficulty. The study area is representative of typical Gambia vegetation. These are the reasons why the study area was preferred for this research.

The study area is near Basse village in the Upper River region. The village is about 275 km NNE of the capital city, Banjul. The village can be strictly defined as semi-urban because of the relatively high population for a village and the socio-economic activities found in the village. The major land use is agriculture involving rearing of livestock and planting of crops. Livestock is freely roaming the forest in search for good pastures. The main source of fuel for the village is fuel wood. Therefore, the rate of population growth threatens the availability of tree biomass resources around the village as it is the main source of fuel and also provides building materials like rafters, fencing poles and bush fencing for the village.

Source: DPWM, 2001

3.4.6 Vegetation and soils

About two thirds of Gambia is covered by the sands which are infertile (Selaolo, 1998; Silitshena and McLeod, 1990). Various types of savanna vegetation cover much of the country. The sand covered area which includes the study area, supports green vegetation consisting of shrub savanna, scattered tree savanna, semi-arid shrub savanna, grass savanna, and dry deciduous forest woodland (Ringrose et al., 1999; Selaolo, 1998) and the high infiltration and retention capacity of the soils (Selaolo, 1998).

Rains in Gambia extend from late June to November and the different vegetation species are fully green by July and December (Ringrose et al., 1990)

However, severe rainfall deficiencies may occur from time to time and large parts of the country may become drought–stricken even for cattle ranching (Government of The Gambia, 1999).

The approach of forest data collection is through manual and field based observations. This approach is labour intensive (Couteron et al., 2001; de Gier, 1989; de Gier, 1995; Hansen et al., 2002; Harrell et al., 1997; Kasischke et al., 1997) in nature hence costly in terms of the length of time spent in the field. A number of approaches have been developed to estimate aboveground biomass of forests and woodlands. These methods differ in procedure, complexity and time requirement depending on the specific aim of estimation operation. Therefore two methods were selected because they satisfied the set criteria for selection (discussed above). The two methods are; the model stem method proposed by Adhikari (2005) originally developed by Montes et al., (2000) and the sub-sampling method by de Gier (1989).

This study is interested in only one tree component, specifically the aboveground fresh biomass with a minimum diameter of 2.5 cm. The smaller branches falling below this diameter and foliage are not considered. Hence the study does not make a distinction between stems and branches.

3.4.7 Model stem method .

Montes et al., (2000) developed a non destructive method in their paper named ‘A non destructive method for estimating aboveground forest biomass in threatened woodlands’. This method is later referred to as Montes method. Adhikari (2005) tested and proposed some improvements in the method. The idea, suggested by his supervisor, Prof. A. de Gier, was to test whether the ambiguities present in coding the tree and its branches differently, and the cumbersome process of measuring the diameter of the branch and the trunk in two different directions based on the tilt angle of the branch can be reduced and the method simplified. The reasoning behind this is that both the stem and the branches are composed of wood and the interest is in the volume of wood irrespective of whether it is in the branch or the stem, and also irrespective of the tilt angle.

. Adhikari (2005) therefore tested whether a single coding scheme could be applied for both the branch and the stem by setting up an experiment using a hypothetical tree of known dimensions. Then Adhikari (2005) concluded that the volume represented by the model stem method, which can be calculated easily, is equivalent to the volume represented by a complex object such as a tree with many branches tilted in many different directions. The model stem method eliminates the problem of counting the number of grids in two different directions to determine the diameter which was necessary in the original Montes method. It also eliminates the need for coding the stem and branches separately. This process reduces a lot of work and the risk of errors that may occur when coding the joints where branches meet the stem. With the original Montes method, a decision has to be taken at these joints as to where exactly does a trunk end and the branch start (Adhikari, 2005). It is against this background that this research work used the model stem approach as described by Adhikar(2005) and Montesetal.,(2000). -Model stem method proposed by Adhikari, (2005).

The method uses Microsoft Excel for windows for data entry (coding), processing (calculations) and for storage of the results. It estimates volume and biomass of an individual tree. The method is based on measurements and calculations made on an ordinary photograph of the tree. It was applied to estimate the volume and biomass of a Thuriferous Juniper tree species (Juniperus thurifera) in Morocco by Montes et al., (2000) and also in Ghana by Adhikari (2005). The method as explained in (Montes et al., 2000) involves 6 major steps as follows;

1. Sampling: Two photographs of each tree from orthogonal views, physical samples of different components of tree (branches and foliage) and tree variable measurements.

2. Calculation of the scale of the photograph.

3. Determination of the volume of the different components of the tree (trunk, branches and foliage).

4. Determination of ‘bulk density’ of these different components.

5. Calculation of biomass for the different components.

6. Validation.

Step 1: Sampling (photographing trees)

The tree in the Montes method is photographed from two orthogonal directions of the axial asymmetry of Juniperus thurifera, the tree in which the method was applied on. The cross section of this tree is often elliptic. The equation of ellipse area is πab where a and b are the half-axes. The equation of crown surface will be $\pi\, a^2$ under its narrow profile and $\pi\, b^2$ under its wide profile, for a given height. The surface area of the ellipse is thus the geometric mean of the two surfaces M = $\sqrt{\pi\, a^2 \times \pi\, b^2} = \pi$ab , the ellipse area. The tree volume is therefore the geographic mean of the volumes obtained from the two photographs. However, for this research only one photograph per tree was necessary due to the axial symmetry of the tree species in the study area. Hence narrow and wide profile calculation was not necessary.

Step 2: Calculation of scale

In the Montes method, the photographs are scanned and the scale calculated. The scale depends upon the size of the grid cells used for data entry, and the resolution used to scan the photograph (in case of an analogue photograph). The scale is obtained from the following equation:

$$S = \left[\frac{D}{R/100} \times y \right] \times C$$

Where, S = the scale ;D= real distance in meters e.g. tree height; R= Scan resolution (in dpi); y= tree height on the photograph (mm); and C = the grid cell size (in mm).

A digital camera was used in this study to take tree photographs, therefore, using the formula described in step 2, was not necessary. Hence, scale was calculated as the simple ratio between the size of the tree in the photograph and the real size of the tree. Since the tree was felled in the field to estimate its biomass using sub-sampling method, the height of the felled tree was measured as accurately as possible using a measuring tape so that it can later be used to calculate the scale of the photograph.

For example the scale was calculated as the ration of the true size of the object to the number of grid cells which represent that size.

Step 3: Volume Calculation

Each photograph of the tree is imported into EXCEL workbook as background image. A grid of known size is then superimposed on the photograph. Each square of the grid is represented by a 'pixel', to which it is attributed a code for different components of the tree. Four kinds of pixels are defined in Montes method with following alphanumeric codes:

• Trunks and vertical or sub-vertical branches = Pixel B (for Branches) Trunks and horizontal or sub-horizontal branches = PixeFoliage = Pixel F (for Foliage.}

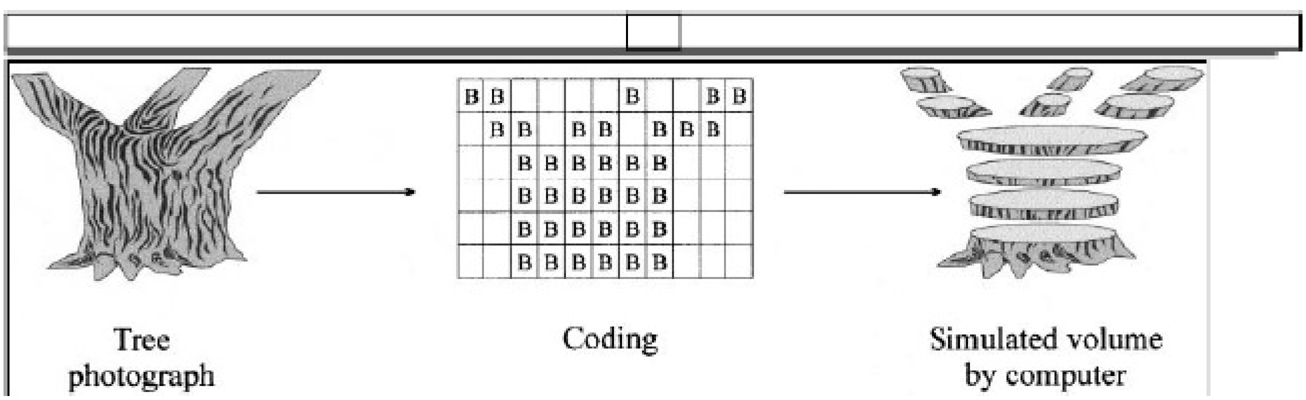


Figure 3-2 The three main steps in the computerization of tree volume (Montes et al., 2000)

• Internal Crown = Pixel M (for Middle of the crown includes inner foliage which can not be seen from outside). The pixel code corresponding to the observed zone of the tree is placed in each cell of the file e.g., if it was a foliage zone, F was recorded in the cell. Pixel M is not coded directly; its volume is deduced from pixel F.

Volume of the trunk (pixel B)

In the EXCEL worksheet, this pixel corresponds to woody components (stems, branches) in a vertical or sub-vertical position. First, the pixel cells are given the value 1. Then every uninterrupted succession of pixels in a row which corresponds to the diameter (d) of a branch or a stem are summed up. This sector is treated as circular section and is applied to the formula of cylinder volume as follows:

$v = 0.25\pi \times d2 \times h$

Where, $h = 1$ (the height of the grid cell)
Then all circular sections are added for the same row (figure 3.2). The branches and trunk volume to a height h (vh) is then given by the formula:

$Vh = \Sigma(0.25\pi \times dn2)$

Where n = number of circular sections for the row under consideration. Therefore, the total volume corresponds to the sum of volumes per row as follows:

$$Vtotal = \sum_{i=1}^{n} Vh$$

Volume of the horizontal branches (pixel H)

Pixel H corresponds to the wood components (stems, branches) in horizontal or sub horizontal positions. The calculation method is same as that for pixel B, but the calculations are carried out down the columns, rather than across the rows.

For the calculation of volumes of the stem (pixel B) and horizontal branches (pixel H), Adhikari (2005) tested and reduced the ambiguities present in coding the stem and its branches differently. Therefore in the model stem method, there is no distinction between stem and branches in a vertical or horizontal position .

Hence the model stem method does not make a distinction between stem and braches.

Adhikari (2005) contends that the interest is in the volume of wood, and this wood is found in both the stem and branches irrespective of the tilt angle.

Therefore during the calculation of volumes for both the stems and the branches, a single code was assigned to both stems and branches treating them as the same entity.

Volume of pixel F [foliage] and M [middle of crown]

Since this research work is considering aboveground woody biomass of dimensions more than 2.5 cm. volume of foliage which includes both 'outside crown' foliage and middle of crown foliage were not calculated.

Step 5 &6; calculation of biomass of each component.

The biomass of both components [stem and branches] was determined from the volume and density. Density is defined by Husch et .al;;[2003] as mass per unit volume expressed in kg/m3.To estimate biomass [kg/tree]. The volume calculated in step 3 is multiplied with the density as follows; B=V x d. where B=the biomass, V= the volume estimated by the pixels for each tissue, and d = the estimated density for each tissue.

The tree sub-sampling method.

Valentine et al [1984] proposed a sub-sampling method that produces unbiased estimates of volume, fresh weight and dry weight of trees. The method was subsequently adapted and improved by de Gier [1989] and applied to trees and shrubs of irregular forms, growing in natural woodlands. The method was found to be very cost effective and overcame many of the identified constraints in biomass determination [de Gier, 1989, de Gier, 1999, de Gier, 2003]. In principle, the method consists of two steps, the first step consists of randomized branch sampling and the second step uses importance sampling. The following is the description of the two steps as described by Valentine [1984] and de Gier [1989].

STEP 1; RANDOMISED BRANCH SAMPLING [PATH SELECTION]

In this step a 'path' is selected through a felled tree, starting from the butt and ending at a terminal bud. A Path is a series of connected branch segments. The branch is the entire stem system that develops from a single bud [lateral or terminal]. This method does not distinguish between a stem and a branch .A segment is defined as part of the branch between two consecutive nodes.

.At every point of branching, a decision has to be made about the continuation of the path.

To determine a path, a selection probability is assigned to each branch emanating from the second node and one is chosen at random. The choice of this branch fixes the second segment of the path. The selection probability of the second segment of the path is denoted as q2 [the first segment of the path has selection probability q1 =1]. The second segment of the path to a node is followed and a branch is selected by randomized branch sampling with probability q3. The randomized branch sampling is repeated at successive nodes until a terminal shoot is selected with probability qn.

SELECTION PROBABILITY.

The selection probabilities assigned to various branches emanating from each node must add up to one. This continuation is selected with the probability proportional to size, [PPS]. ‘Size’ here is equivalent to a proportional measure of the biomass in each of the possible path continuations and can be approximated by d2l , where d = diameter at the base of the branch and l is the length of the branch. However, de Gier [1989] found that in the field, the most burdensome activity was the measurement of length of branches of the felled tree for path selection. This is because sometimes when a tree falls, the branches are broken. Therefore the same source made an importance alteration in the computer program designed, whereby for path selection, an estimate of biomass was no longer based on d2l, but on a power of d where d2.l =a .d b.

Example of how the selection probability is executed. Suppose a tree with a single stem [x] is used for path selection. At the first node above the ground a branch [y] originates from the main stem. This makes two possible paths continuation, each of which will be called a branch. Assuming that each of these branches’ [x and y] base diameter are d =7 cm and d =5 cm respectively, and a random number is drawn, say 0.678 then applying the formula a*db where a is the random number and b is a constant found by de Gier [1989] to be 2.6689, then x and y become 122.09 and 49.74 respectively. Based on the PPS then branch x which happens to be main stem is selected. The path continues to the next node where the procedure is repeated. Path selection terminates when a terminal bud is reached, in this research work, when a minimum diameter of 2.5cm is reached.

The selection probability assigned to a branch is the conditional probability of selecting that branch given that the path has reached the node at which the branch arises. The unconditional probability of selection for the Kth segment included in the path is; Qk = $\prod_{r=1}^{k}$ q r

The biomass of all the above ground components of a tree can be estimated from a single path. However, at least two paths are needed to estimate within tree standard errors. , Therefore, estimated fresh weight of a tree can be calculated as follows. b =∑ b k / Qk. Where Qk is the unconditional selection probability for the Kth segment of the path and bk is the weight of the kth segment.

Step 2; Importance sampling.

In this step, the method uses importance sampling, leading to the removal of only one randomly located disk. Importance sampling is a continuous sampling with probability proportional to size. This means that the path of the tree is considered to consist of an infinite number of infinitely thin disks of which one is to be selected with a probability proportional to its diameter squared.

Estimating tree woody biomass volume.

In the path, points are located where a change of taper occurs [notably at the butt and just before and after nodes]. The diameter is measured at each of these points and the distance to the butt is recorded. From the latter, the distance between any two successive points can be calculated. For each point of measurement, the diameter squared is divided by its unconditional probability assigned to the segment in which the point is located. This quantity is defined as “inflated area ”. For every two subsequent points, two such inflated areas are calculated. Since the distance between two successive points is known, the inflated volume of the corresponding woody section can be calculated. Adding these volumes together, results in an estimate of the total tree woody volume.

Locating the points for disk removal.

For the weight estimate, segment or a disk has to be removed at a random point along the path. This point is determined by multiplying a random number by the estimated total tree woody volume. The segment of the path in which this volume is reached is first identified.

Estimated tree woody fresh weight.

A disk of approximately 10 cm is removed. The disk can be split into any number of wedges if it is large, normally up to 4 wedges. The wedges are then weighed individually and one wedge is selected with a probability proportional to wedge fresh weight. The weight of the selected wedge [kg] per unit thickness [m] is determined and divided by its unconditional probability value assigned to the segment from which it is removed resulting in the estimate of the disk fresh weight, from which tree fresh weight can be estimated. The estimate of the tree woody fresh weight is calculated by multiplying this value with the estimated tree woody volume [m3] , and by dividing it by the square of the disk diameter [m2].

Estimating tree woody dry weight.

The dry weight of this disk can be determined after oven drying. This allows for the calculation of estimated dry weight of the tree, in the same manner as fresh weight was estimated. Thus unbiased estimates of the tree woody volume, tree woody fresh weight and tree woody dry weight are obtained. Though this method appears complicated, [de Gier, 2000] simplified it by designing a program which is installed into an iPac [portable hand-held computer] and guides the user through all the steps until fresh biomass and wood volume are estimated in the field. The user has to understand the concept but does not need to do the calculations; hence the method is user friendly.

Complete tree harvesting method.

This method involves complete harvesting of randomly selected plots or individual trees within plots. In this method the woody biomass of a tree is measured after completely felling the tree, dividing it into its manageable component parts [wood of different sizes] weighing their fresh biomass, then oven drying samples of each component to determine moisture content from which dry weight can be calculated [Stewart et al;1992

Logically, it is too time consuming to measure a whole tree in this way. This method was used in this research work to validate model stem and sub-sampling methods under the assumption that biomass obtained through complete harvesting method is flawless.

Next, a comparison was made between measured aboveground biomass [kg/tree] obtained through complete harvesting method and estimated biomass [kg/tree] obtained through an equation developed in this research. This comparison was also extended to estimated biomass [kg/tree] obtained using Tietema's mixed-species equation developed in Botswana [Tietema, 1993] and estimated biomass [kg/tree] obtained using Brown's mixed-species equation for tropical regions [Brown, 1997] .

Tietema's biomass equation.

Tietema [1993] developed biomass regression equations for 14 tree species in Botswana, covering mostly the hardveld on the eastern margin of the country. The description of the method as described by Tietema [1993] is as follows. Trees were cut and their total fresh weight [including all the tree components such as stem, branches and foliage] were taken with a spring balance mounted on a crane fitted on the truck. The height and the diameter of the trees were measured before cutting. The crown was measured twice along two perpendicular axes and the average of these two measurements was considered as the crown diameter. The crown basal area was calculated from this crown diameter. The stem diameter was measured at ankle height [dah =10 cm aboveground] and this measurement was used for calculating the stem basal area. Regressions were calculated as linear regressions after logarithmic transformation. A power curve of the form; B = 0.1936 X BA 1.1654 was obtained for mixed-species where B = aboveground fresh biomass [kg/tree] and BA = basal area calculated from the dah.

Brown's tropical region equation.

Brown's biomass equation was developed for dry zones with rainfall less 900mm/year [Brown, 1997]. The equation was revised by [Brown, 1997] from Martinez-Yrizar et al; 1992 for dry forest in Mexico. A total of 371 trees of many species with dbh ranging from 5 to 148 cm obtained from ten different sources and from all the tropical regions were used [Brown, 1997] to developed the following biomass equation for mixed-species

; $Y = 10^{[-0.535} + \log10$ [BA], Where Y = The aboveground biomass [kg/tree] and BA = basal area calculated from dbh.

3.4.8 ASSESSMENT OF OPTIONS TO MITIGATE CONCENTRATION OF GREENHOUSE GASES IN THE GAMBIA

On the basis of the assessment, a total of 181 Gg of CO_2 were emitted into the atmosphere while about 50,000 Gg of CO_2 were removed from the atmosphere by various socio-economic activities conducted in The Gambia in 1993 (NCC, 2002). This indicates that The Gambia is a net source but the forestry sector is a net sink of CO_2. Considering the size of The Gambia, the net absorption of over 50,000 Gg of CO_2, per year from the land-use change and forestry category should be seen as a sizeable contribution to the removal of GHGs from the atmosphere. The Gambia is also contributing to the stabilization of their concentration in the atmosphere. This is a clear indication that there is need to identify changes in the land-use policy, law and tenure that significantly influence and encourage forest conservation and sustainable management. Non-GHG reduction objectives such as preservation and enhancement of biodiversity, soil conservation, watershed

Management could also be looked into. A mitigation assessment typically focuses on long-term opportunities for reducing GHG emissions or enhancing carbon sinks. In an effort to meet the requirements of the researcher but taking particular consideration of the national needs for sustainable development the researcher designed the mitigation assessment to satisfy the needs of the various possible users or stakeholders. The primary users of the assessment will be policy- and decision-makers.

The first step in the assessment of mitigation was to gather data and information through stakeholder consultation and desk review of literature on mitigation of greenhouse gases. The consultations were conducted at both the community and technical levels and was largely based on the 1993 Inventory of Greenhouse Gases (NCC, 2002). This culminated in the identification of a long list of potential mitigation options that could be stand-alone projects or could be collapsed into a single project. Based on desk review and scoping meeting involving various stakeholders, the following list of categories of mitigation options were developed and screened for further analysis.

1: Residential Sector

(a) Switching to Energy Sources/Equipment with Lower GHG Emissions.

2: Energy

(b) Switching and promotion of renewable (Solar Home Systems and LPG).

3: Transport Sector

(c) Revitalisation of River Transport for movement of passengers and bulk cargo.

4: Agriculture Sector

(d) Water management in rice cultivation and maintenance of soils.

5: Rangelands and Livestock Sub-sector

(e) Rehabilitation of degraded rangelands including afforestation, reforestation, grass and shrub establishment, control of grazing lands, halophyte establishment on salinized lands, etc.

(f) Improving the quality of the diet through mechanical and chemical feed

processing and strategic supplementation.

(g) Improve production using enhancing agents and improved genetic characteristics.

(h) Improved production efficiency through improved reproduction.

6: Forestry Sector

(i) Forest protection and conservation and increase efficiency in forest management.

(j) Reforestation, afforestation and agroforestry.

(k) Urban and community forestry.

7: Waste Management Sector

(l) Landfill management.

(m)Waste recycling.

(n) Waste composting. In screening this long list of mitigation measures, national and project screening criteria and indicators were used to reduce the long list of potential mitigation measures to a manageable list of potential projects. The criteria included the availability and ease of collecting the data needed for project development and implementation, the benefits and costs of the projects, the economic and social importance of the project in Gambia, and, most importantly whether the project meets the dual objectives of sustainable development and reduction of the concentrations of GHGs in the atmosphere.

The additional national indicators used include:

> national development benefits and policy priority;

> how well the projects span the range of GHG mitigation opportunities in the country;

> how representative these projects are of GHG mitigation opportunities in the country or sub-region as a whole; and

> the availability of information to assess these projects.

The outcome of the screening was the reduction of the 11 options to the following 8 options that were then subjected to in-depth analysis using benefit-cost and cost effectiveness.

(i) Rural electrification using Solar Home Systems to displace a planned diesel plant.

(ii) Greenhouse gas reduction through the use of Improved Cooking Stoves.

(iii) Carbon sequestration through reforestation and protection of existing forests.

(iv) Large scale introduction of Liquefied Petroleum Gas to displace fuel wood.

(v) Utilizing waste for two city authorities to generate landfill gas for bottling.

(vi) Integrated crop and livestock farming- utilizing rice straw (treated with urea) as cattle feed.

(vii) Managing a multi-product forest for cashew nuts, honey-bee-keeping, etc.

(viii) Waste management using composting.

The in-depth analysis of the eight options consisted of assembling data for the base year on the activities and technologies/practices that are associated with GHG emissions or carbon storage. The assembly of base-year data was also heavily dependent on the 1993 Inventory of Greenhouse Gases (NCC, 2002) and other sectoral data and information. After the base year data and information were documented in some detail, then, attempt was made to project and evaluate the future. The development of scenarios of the future requires data on the activities that resut inGHGemissions or shape opportunities for carbon storage. Various criteria were applied to screen the list of options during the in-depth analysis.

At the screening stage, a rough assessment of the potential attractiveness of options was made using the matrix shown below.

The matrix provides a qualitative indication of the attractiveness of each option by ranking it very low (1), low (2), medium (3), high (4) and very high (5) as judged according to each criterion.

A quantity assessment used scoring method that varies from 1 (lowest) to 10 (highest). The score is multiplied by the weight to give a total score for particular criteria. According to the example below, the highest possible score was 30 and the project scored a total of 21.5 thus attaining 72% of the maximum score. This implies that the project is viable and could have wide scale application.

Cost-effectiveness analysis was also conducted to identify the least-cost option for reaching a goal. A typical tool used to assess cost-effectiveness is a decision matrix that analyzes the cost-effectiveness of mitigation options by comparing costs with benefits of the options measured in a common metric. The measurements are added up across the different policy objectives (and weighted based on relative importance) and compared to costs to determine cost-effectiveness and the options are ranked.

To utilize the matrix one determines the options to be examined, the objectives for which the options will be scored and the relative weights associated with each objective, the scenarios which may be part of the analysis and the costs of each mitigation option. Once these have been determined and entered into the table, one can begin scoring the measures on a scale of 1(very low) to 5 (very high) indicating how well each measure meets each objective under different scenarios. The decision matrix then automatically calculates weighted scenario scores for each option. A total score is also calculated. Cost-effectiveness is also automatically calculated by dividing the cost of the option by the incremental (mitigation scenario – current policy scenario) total score.

Throughout the analysis costs and benefits were typically expressed to occur over a period of time in terms of their net present value (NPV), which was calculated using a discount rate (DR). The DR reflects the return on foregone present consumption that is scarified to secure future consumption. In this research work, an appropriate DR of 10% was used to evaluate the present value of monetary costs and benefits of the mitigation options. In order to assess an option's cost-effectiveness, the discounted costs and benefits are related to its GHG savings or carbon storage.These costs and benefits are quantified where possible or at least described qualitatively where quantification is not possible

Where the benefits of the mitigation options with regards to climate change could not be monetised the benefits were stated simply in terms of either carbon abated or stored.

Stabilization of the concentrations of greenhouse gases in the atmosphere at all levels will eventually entail substantial reductions in CO2 emissions. Long term stabilization of atmospheric CO2 concentrations requires that net anthropogenic CO2 emissions ultimately (over centuries) decline to the level of persistent natural sinks, which are expected to be less than 0.2 PgC/yr (IPCC WG I TAR, 2001). IPCC (2001) concludes that temperatures will continue to warm decades after the CO2 concentrations have stabilized due largely to thermal inertia. As temperatures are projected to increase decades after stabilization of concentrations of CO2, climate change will not be obviated and, therefore, adaptation will be necessary to minimize damages and to maximize opportunities.

In this research work, the GRADS software was used to develop climate change scenarios. Only the equilibrium General Circulation Model (GCM) outputs are used to create the climate change scenarios. Outputs from five GCMs were run to obtain 1*CO2 and 2*CO2 outputs for temperature (and the difference 2*CO2-1*CO2), rainfall rates and solar radiation (and the ratio 2*CO2/1*CO2) for creating 2*CO2 equilibrium scenarios. The models ran are the Canadian Climate Centre Model (CCCM, Boer et al., 1992), Goddard Institute for Space Studies (GISS, Hansen et al., 1983), United Kingdom Meteorological Office (UKMO, Wilson and Mitchell, 1987), the Geophysical Fluid Dynamics Laboratory (GFDL) equilibrium run (GFD3, Mitchell et al., 1990), and the Hadley Centre General Circulation Models with greenhouse gases alone (HCGG, Hagler Bailly Services, Inc, 1997), and with sulphate aerosols (HCGS, Hagler Bailly Services, Inc, 1997). The GFDL 1% transient model (GF01, Gates et al., 1992) was also ran just to visualize the transient behaviour. To choose the models that best estimated the climate of The Gambia, the 1*CO2 temperature output from all the seven models was compared with the 1951-1990 temperature data .

. The GFDL (equilibrium, GFDL30 and transient, GFDL01), CCCM, HCGG, and the HCGS models were the five models that best approximated the climatology of The Gambia. Statistical analysis shows correlation coefficients of 0.84 for CCCM, 0.92 for GFDL30, 0.85 for GFDL01, 0.83 for HCGG and 0.81 for HCGS models. Only four GCM models (GFDL, CCCM, HCGG, and HCGS)1 were recommended for use in the vulnerability study in The Gambia.

On the average, by 2075, mean temperature of The Gambia is projected to increase by 3^{o}C to 4.5^{o}C depending on the GCM used. By 2100 a decrease of 59% (HCGG), 17% (HCGS) and 15% (GFDL equilibrium model), and an increase of about 15% (GFDL01) and 29% (CCCM) about the 1951-1990 average rainfall amount are projected in The Gambia .

Little change is estimated in solar radiation (-0.4% (GISS), -5% (GFDL-equilibrium), and 6% (UKMO)) and PET (+1% CCCM and GFDL-equilibrium, -5% HCGG and -3% HCGS).

The vulnerability and adaptation assessment started with a training workshop, which was followed by data and information collection on crops and crop management practices. To have location specific soils' data, soil specialists of the Soil and Water Management Unit (SWMU) of the Department of Agricultural Services (DAS) were contracted to conduct a study on soils in the study sites. Data on rainfall, solar radiation, temperature and sunshine hours were collected from the DWR. Sites identified and used in a previous assessment (Jaiteh, 1997) were maintained for this study and they are Bakendik, Kuntaur, Giroba Kunda and Somita. These sites represented an area where one of the crops was predominantly cultivated. The climate change impact analysis of the crop production sub-sector of Agriculture made use of the GCM scenarios from the CCCM, GFDL30, HCGG and HCGS models. These scenarios, socio-economic data and crop production data were input into the DSSAT3 biophysical model to run the simulation of impacts of climate change.

3.4.9 Background on biodiversity and wildlife

The small size of The Gambia (~11,000 km2) makes it very difficult to get an adequate home range of many faunal species, especially the big game, and as a result they cannot be found in the wild. Many parts of the country have already been devoid of forests. Only 42% of the country is covered with forest and this includes the seven Protected Areas (PAs) of the country.

The study is located in the first protected area to be established in The Gambia, Abuko Nature Reserve, which was gazzetted in 1968. Due to growing awareness about the importance of conserving what remained of the country's flora and fauna, the Government created a Wildlife Conservation Unit under the DOF. This Unit was upgraded into a government department (Department of Wildlife Conservation) in 1977 and re-designated in 1994 to the Department of Parks & Wildlife Management (DPWM) to reflect its widening role into wildlife management as well as conservation. As well as being accountable for the management, administration and development of The Gambia's seven PAs, the department also handles all matters relating to wildlife conservation and management.

This includes the enforcement of the 1977 Wildlife Act, which prohibits the sale of wildlife products and the keeping of wild animals in captivity. The department also controls and monitors hunting activities in the country.

The current checklist of animals in The Gambia, compiled by Barnett and Emms (2000) indicates that there are 104 mammal species. However, certain species such as the African Lion, Wild Cat, Red River Hog, Roan Antelope and Red-fronted Gazelle have become extinct. The checklist further indicates that there are 549 bird species, 59 reptile species (with 32 snake species) and finally 27 amphibian species.

To date, PAs comprise more than 4% of the total area of The Gambia .The latest wildlife policy aims at increasing this to 5% with a proportional regional distribution. The parks and reserves of The Gambia have been specially chosen for the endangered nature of the habitat type and/or species found within them. The intention is to provide a safe haven for flora and fauna to flourish without undue interference from human beings. A limited range of resource utilisation by local communities is permitted, provided this is compatible with the aims and objectives of the PA concerned.

3.4.10 Impacts of climate change on habitat and species

The methodology used involves the application of the Habitat Suitability Index (HSI) model developed by the United States Fisheries and Wildlife Department (USFWD). HSI is a software package that combines cover-types and sub-area cover-types with their respective lexicon variables. Cover-type refers to the surface cover (water, vegetation, sand, rocks, etc.) of the study site and the parameters are in-built in the software. Initially, 10 animal species (fauna and avi-fauna) were entered as model inputs covering an associated 20 cover-types (with sub-area cover-types).

The type of fauna species used in the study include Bushbuck, Dwarf Crocodile and Green Sea Turtle while the avi-fauna include Bateleur, African Spoonbill, Turaco, Crowned Crane, Great White Egret, Sacred Ibis and Osprey. These species were selected based on their similarity (phenotypically) with some of the 120 animal species used to develop the HIS model. Most of the values entered for the variable lexicons as input are default values primarily due to lack of required data. However, successful parameterization and results under the current temperatures were obtained for only 5 species namely: Dwarf Crocodile, Great white Egret, Osprey, Bushbuck and Turaco.

Abuko Nature Reserve 134 Western Division Tanji River (Karinti) Bird Reserve 612 Western Division Bao-Bolong Wetland Reserve 22,000 North Bank Division Kiang West National Park 11,526

Lower River Division River Gambia National Park 589 Central River Division Nuimi National Park 4,940 North Bank Division Tanbi Wetland Complex 6,000 Western /Kombo St. Mary's Divisions.

Source: DPWM, 2001

The suitability of the habitats for the Dwarf Crocodile and Osprey species will be highly reduced under the projected climate change scenarios. Migratory species such as the Osprey may be especially vulnerable because they require separate breeding, wintering, and migration habitats. In many cases, one or more of these habitats could be at risk because of climate change and other reasons.

Various strategies are available to help conserve wildlife and biodiversity. These include the establishment and maintenance of PAs (in situ conservation), active management of wild populations outside PAs (inter situ), and maintenance of captive populations (ex situ methods) (IPCC, 1996). Of these, the highest priority should be placed on in-situ and intersitu conservation.

The adaptation strategy should be developed within the context of global, regional and national biodiversity conservation priorities. A large number of habitat management and intervention techniques can be used as part of an overall adaptation strategy. Many habitat management and intervention techniques are already in use in PAs managed by DPWM and the techniques themselves can be adopted for use under a new set of climatic conditions. The following adaptation measures are recommended:

1. Develop strategies that seek to maintain ecological structure and processes, maximise evolutionary and ecological potential in species and ecosystems, and increase ecological resilience;

2. Maximise reserve connectivity, size, and number; discourage fragmentation and encourage corridors that will serve as habitat migration lanes; and

3. Adopt flexible zoning of reserve boundaries and develop more effective buffer zone management.

The coastal area of The Gambia extends 80 km from Buniadu Point and the Karenti Bolong in the north, to the mouth of the Allahein River in the south [, Whyte and Russel, 1988). It has 70 km of open ocean coast and about 200 km of sheltered coast along The Gambia River. The sheltered coast is dominated by extensive mangrove systems (66,900 ha), and mud flats. Only about 20 km of the coastline is significantly developed and this includes Banjul (the capital city), Bakau and Cape St. Mary, Fajara and the Tourism Development Area (TDA).

Thirteen hotels and tourist resorts have been built on this stretch of the coastline. Elsewhere, the coastline is largely underdeveloped except for some fish landing sites and cold storage infrastructure used to process and store fish and shrimps. The coastal zone contributes significantly to the economy of The Gambia. During the period of October to May, The Gambia receives more than 100,000 tourists, all beach resorts and hotels are operational, and the industry is estimated to employ about 100,000 people either directly or indirectly.

3.4.11 Impacts of climate change on rangelands and livestock - Assessment

Methodology

In this study, the approach used to assess impacts of climate change to rangelands and livestock in The Gambia consists of a simulation technique using the second generation Simulation of Production and Utilization of Rangelands (SPUR2) Model (Hanson et al, 1992). SPUR2 was developed by the USDA-ARS Great Plain Systems Research Unit and Colorado State University as a general rangeland ecosystem model that simulates the cycling of carbon and nitrogen through several compartments, including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. It also simulates competition between plant species and the impact of grazing on vegetation. The model also simulates the direct effects of CO2 on plant production.

The SPUR2 model consists of five basic components: hydrology, plant growth, animals (domestic and wildlife) and economics. The hydrology/soils component calculates upland surface runoff volumes, peak flow, snow melt, upland sediment yield, and channel stream flow and sediment yield. Soil water tensions, use to control various aspects of plant growth, are generated using a soil water balance equation. The soil conservation service curve number procedure computes surface run off, and soil loss is computed by the modified Universal Soil Loss Equation (USLE). The plant component of the model is a deterministic set of equations and relationships that can simulate the dynamics of both cool-season (C3) and warm-season (C4) plants. With small exceptions for computational efficiency, the model processes each plant species in the simulation in exactly the same manner. All species growth, death, and physiological dynamics are calculated the same way, no matter whether the species is C3 or C4. The species' responses to temperature, moisture, nutrients, etc., are simulated by supplying a set of parameters and critical values for each plant species to be simulated. These parameters and critical values are used to distinguish the physiological and ecological differences between plants, and are in effect for the entire simulation.

The SPUR2 model has the capability to simulate the effects of grazing by wild as well as domestic animals. In this research work, only the wildlife component is used as all domestic animals are grazed in the open. The model uses wildlife as a sink for the removal of vegetation and only standing green and standing dead biomass are considered to be forage available for harvest by wildlife.

The methodology for implementing the assessment of climate change impacts on rangelands/livestock is divided into the following nine steps as shown.

Step 1 determines the areas of the country in which the simulation sites will be located. Location of sites is determined in part by the availability and completeness of data for the simulations. These data include weather elements, soil and vegetation data. Four sites were located in this research, but only one site has been analyzed and discussed in this report.

Step 2 determines the initial conditions for the simulations using the plant, soil and livestock models.

Step 3 defines indicator variables, which include peak standing crop, water use efficiency, soil organic matter, forage intake, etc.

Step 4 is parameter estimation and model validation. Types of curves needed include monthly standing crop, forage crude protein or nitrogen, and yearly peak standing crop.

Step 5 selects representative simulation sites. Four sites were selected but only the results of one site are analyzed in this report..

Step 6 conducts the simulation experiment. The number of simulations includes a normal simulation, which uses an unaltered version of the historical weather file, and simulations using climate change scenarios.

Step 7 compares the difference between the “normal” and climate change scenario runs.

Step 8 tests adaptive strategies, which depend on the current and accepted management strategies within a country and the type of livestock being studied.

Step 9 develops policies to mitigate the negative impacts or to take advantage of possible positive impacts of climatic change

. Economic analysis can be conducted to examine the effects of climatic change on the local or producer level, at a more aggregated level to examine the effects of secondary supply and demand within a region or country.

However, economic analysis was not conducted in this research due to limited knowledge in econometrics. Forty years of historical weather data are used for each simulation site. The data includes daily maximum and minimum temperature (oC), rainfall (mm), wind run (km/day), and solar radiation (Langleys). Data for the hydrology model includes soil name, type, and texture; slope; percentage of sand, clay, and silt; organic matter; parameters for USLE; soil evaporation; bulk density; and water holding capacity at 15 bar. Plant model initial conditions include biomass estimates for green shoots, live roots, propagules, standing dead, dead roots, litter, and soil organic matter as well as an estimate of the amount of nitrogen (g/m2) in green shoots, live roots, propagules, standing dead, dead roots, litter, soil organic nitrogen, and soil inorganic nitrogen.

In this simulation, domesticated animals in The Gambia are classified as wildlife because of their feeding characteristics over an extensive and unmanaged area. Data for the wildlife component included animal weight, forage intake, preferred grazing sites, etc. Where climatological data are missing, interpolation is used to fill the gaps. In some cases abiotic and biotic data to be used in the simulation are unavailable and in such situations the default data provided in the model are used.

SOURCE---GOOGLE EARTH IMAGE

3.5 CONCLUSION.

The assessment of the key studies has shown that sustainability aspects were only inadequately taken into account in existing biomass potential assessments. None of the studies included all three dimensions of sustainability (environmental, social, and economic) nor did any of the studies cover all relevant aspects of one dimension

Generally, environmental factors were overrepresented whereas social and economic aspects were taken into account far less frequently. Regarding the environmental dimension, biodiversity, and climate aspects were included more often than soil and water aspects. Regarding the social dimension, many studies accounted for the competition of biomass and land with food which always was given priority. Although many studies assessed economic aspects, only a few calculate the impact of bio energy production on crop and food prices by integrating bio energy production in the whole market system.

In almost all key studies assessed the integration of sustainability criteria lead to a reduction of the biomass potentials. The potential was reduced due to restricting the area available for biomass production or due to yield reductions. However, two studies showed that reductions can partly be compensated with biomass which is derived from the management of conservation areas.

Among others, three factors contributed to the fact that sustainability was accounted for only partly: the complexity of the system due to feedback mechanisms and linkages between the three dimensions of sustainability, the fact that approaches and methodologies were suited to different extents for the integration of sustainability in a comprehensive way, and finally the lack of comprehensive and exact definitions regarding certain aspects.

Resource assessment and supply analyses are important factors in determining energy inputs and outputs, environmental impacts, and most importantly, the economic feasibility of biomass-related production and utilization scenarios. Quantitative assessment and cost of delivery associated with each individual and applicable biomass resource within a set distance of a conversion facility is critical to optimizing and maximizing the energy returns, environmental enhancement, and economic feasibility. This assessment estimates quantities of various biomass resources throughout the Gambia or regional basis for use as feedstock for liquid fuel (transportation) production. The estimates are used to generate potential supply curves, calculate the effect of biomass and crop production on water use and carbon dioxide emissions, and provide quantities and supply curve data for an integrated GIS analysis.

And finally, the assessment examines the impact that bio energy crop production (grain and Stover/straw) has on water use and carbon dioxide emissions due to irrigation and emissions of CO2 from crop planting/establishment, field maintenance, and harvesting.

Evaluating the economic feasibility of biomass resources (i.e., plant material) as an energy source requires comprehensively addressing transportation costs by integrating that cost information based on the type of biomass material, the distance it must be transported, and the available transportation infrastructure. GIS is well suited to this type of analysis

CHAPTER 4

4.0 ANALYSIS OF DATA AND TEST OF HYPOTHESIS

4.1 INTRODUCTION.

Biomass resource assessment is essential in evaluating the bioenergy potential in a given location, the social and environmental impacts associated with resources production and (most importantly) the economic feasibility of biomass utilization scenarios. Biomass resource assessments guide industrial development strategies and support decision-making processes.

Biomass resource assessment products have different information characteristics and applicability. These products can be presented in a different format: tabular, graphic (charts or graphs), geographic (maps), or as analytical tools and software products. The assessments vary depending on the purpose and the level of detail required. The purpose of an assessment is to identify resource potential within a given area for a particular end use: power, heat, steam, or transportation fuel. There are three types of biomass resource potential: theoretical, technical, and economic, that build on each other in providing a comprehensive view of biomass energy opportunities.

Theoretical -Illustrates the ultimate resource potential based on calculation or measurement of the net primary productivity of the biome.

Technical -Limits the theoretical resource potential by accounting for terrain limitations, land use and environmental considerations, collection inefficiencies, and a number of other technical and social constraints. This type of potential is also called accessible biomass resource potential.

Economic – It is a subset of technical resource potential that applies economic parameters, which estimate the cost of biomass resources either at the field or forest edge. The final outcome of this type of assessment is a supply curve (GMD/tonne).

The level of detail varies between biomass resource assessments. High-level, aggregated information - such as assessments at economy-wide, regional, and province level - are usually required by policy makers. Whereas more detailed information at a country/region or site-specific level is required by energy planners and project developers.

The purpose of a biomass resource assessment and the level of detailed required dictate the method employed to assess biomass resources. The current evaluation methods include geospatial technologies, field surveys, and modeling.

Geospatial Technologies. These include remote sensing (RS), geographic information systems (GIS), and global positioning systems (GPS). Remotely sensed images, such as aerial and satellite images, provide an efficient and reliable way to monitor biomass resources over time. Remote sensing images have relatively fine spatial and temporal resolutions, similar to the data obtained by field surveys. These products range in spatial resolution from as coarse as every degree of latitude and longitude to as fine as every six meters, and can be at repeatable time scales. RS is the only technique available to monitor biomass resources at local, regional and global scales. This technique is used to estimate growing stock of biomass and forecast its productivity. RS provides a cost-efficient way to collect the required information at areas that are remote and poorly accessible. Remote sensing images are also the only practical approach to analyze land use and land cover change at economy-wide, regional, and global scales. Their patterns can be studied by comparing images acquired at different times.

Data derived from remote sensing images, such as land use/cover, elevation, and surface temperature, is further used in geographic information systems (GIS). GIS is a computer-based information system used to create, manipulate, analyze, and visualize geographically referenced information. It is a powerful tool for assessing biomass potential: It integrates many different types of data and provides a means of examining their spatial relationships. The concept of data overlaying in GIS is shown in Figure 1; GIS is particularly useful in estimating technical biomass resource potential by integrating various datasets such as crop/forest production statistics, land use, terrain, transportation infrastructure, and protected areas. It can also identify areas where the agro-climatic conditions are suitable for growing a particular crop or assess biomass resources available within a certain radius from a processing facility.

Surveys. Field surveys are used to collect data as part of site-specific evaluation. Usually, a field plot (the size can vary) is selected as representative of the vegetation type in a study area, and parameters such as stem diameter, tree height, or crown dimensions for forest resources and density, height, and phonological development for crops are easily measured. The results are further extrapolated over a larger area and used to develop equations that predict biomass availability. This sampling technique provides the most accurate estimate of biomass resources at a given location; however, it is not practical for broad scale inventory. It is a time-consuming, labor-intensive, and therefore costly procedure, even with today's satellite communication technology (GPS).

Data collected by the GPS operations can be automatically recorded with a GIS program to further analyze the data or validate model-derived estimates. Currently, field surveys in biomass resource assessments are used when other methods prove insufficient or when capabilities to use other methods don't exist.

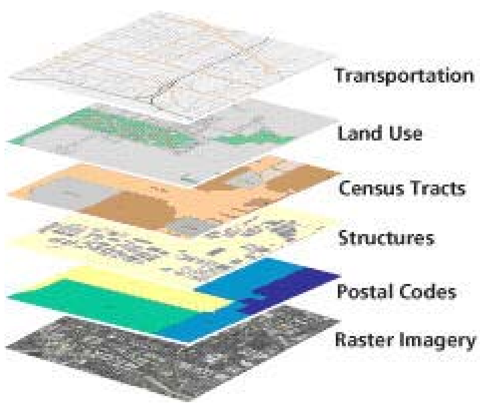


Figure 4.1 -conceptual model of GIS.

Another way of collecting field data is sending questionnaires to farmers and cooperatives and asking them to report information such as planted acres, harvested yield, harvesting methods, and water management (irrigation or no irrigation). But this method of collecting field data relies on voluntary participation, creating a potential for informational gaps. Information can also be collected by face-to-face and telephone interviews, which are only applicable to local surveys; otherwise, it could be a time-consuming process. The "paper" survey method is often used for collecting crops-related information while the sampling technique described above is usually applied in forest resource estimates.

Modeling. Models are simplified frameworks designed to illustrate a system or process often using mathematical techniques to facilitate calculations or predictions.The complexity of a model and the modeling technique depend on the needs of the assessment and data availability. Models can be as simple as extrapolating measured data using statistical methods, or as complex as balancing numerous processes (organized in separate modules) to derive resource characteristics. Both static (analytical) and dynamic (simulation) models are used in biomass resource assessments. Static models describe a system mathematically, in terms of equations, and can be built in a spreadsheet. An example is estimating the amount and cost of crop residues (rice straw for example) by specifying values (usually averages) for several variables such as crop production, residue generation, labor cost, and prices (chemical, fertilizer, fuel, and planting).

Simulation models describe a system dynamically over time and are built using specific software. While static models ignore time-based variances and the synergy of the components of the system, dynamic models explore “what-if” scenarios and the sensitivity of a system to variations in its different components as time progresses. For example, simulation techniques can be used in a crop-simulation model to examine the effects of climate, soil, and management practices on crop production. Another example is the use in biomass resource elasticity studies to examine the effect of land use change, market price, and policy measures on feedstock supply. When combined with optimization algorithms, simulations can indicate what policy choices or other decisions may lead to particular desired outcomes.

A more advanced, and perhaps the most comprehensive, type of modeling is the integration of simulation techniques with GIS to capture temporal and spatial perspectives of a system together. For example, incorporating soil type, climate, land use and road network information with advanced transportation and economic models, it is possible to predict both where dedicated energy crops could be grown and their marginal cost. Depending on the purpose of the model and input data resolution, the GIS system allows visualization of the outcome at different geographic levels – regional, sub-regional, economy-wide, state, provincial, municipal, or site specific.

In the past, using the modeling method for biomass resource assessments has been criticized for relying on highly simplified assumption Today however, simulation models allow examining the theoretical consequences of more complex assumptions. Increased computational power and speed of today's computers has vaulted dynamic modeling ahead of static modeling as the method of choice, and made it possible to improve intuition about the feedback and interaction among regions, sectors, and other components of the biomass “landscape”. Moreover, data are becoming organized into common databases at finer levels of granularity and sharing data has never been easier. Micro-data can now support micro-simulations. It is possible to compute large-scale micro-simulation models that would not have been possible just a few years ago.

In Gambia, the forest inventory carried out uses a sampling intensity of 0.1%. A total of 110 sample plots of 0.07ha each were established temporarily throughout the forest. The plots were allocated for each village forest based on the proportion of the forested village area to the total forest area. The plot layout in each forest was systematic. In each forest, a transect was established in vegetation types that showed distinct differences, and plots laid out at convenient distances depending on the size of the forest. The sample plot comprised of four areas of measurement. In the innermost sub-plot with 2m radius, all types of plants including trees, shrubs, herbs and grasses were identified and recorded. Within the 5m radius subplot, shrubs and saplings with diameter at breast height (DBH) of less than 5cm were identified and recorded. In the middle and outer subplots, with radii of 10m and 15m respectively, trees with DBH greater than 10cm and 20cm respectively were identified and measured for DBH and total height of sample tree (a tree nearest to the plot centre). Furthermore, the species name (botanical) were recorded along with the number of stems.
Before computation of various stand parameters, a checklist of tree and shrub species was prepared for the entire forest. Each tree was then given a code number for subsequent calculations. Since only sample trees were measured for total height, a height/diameter relationship was established and the equation was used to estimate the height of trees that were measured for DBH only. The equation was:

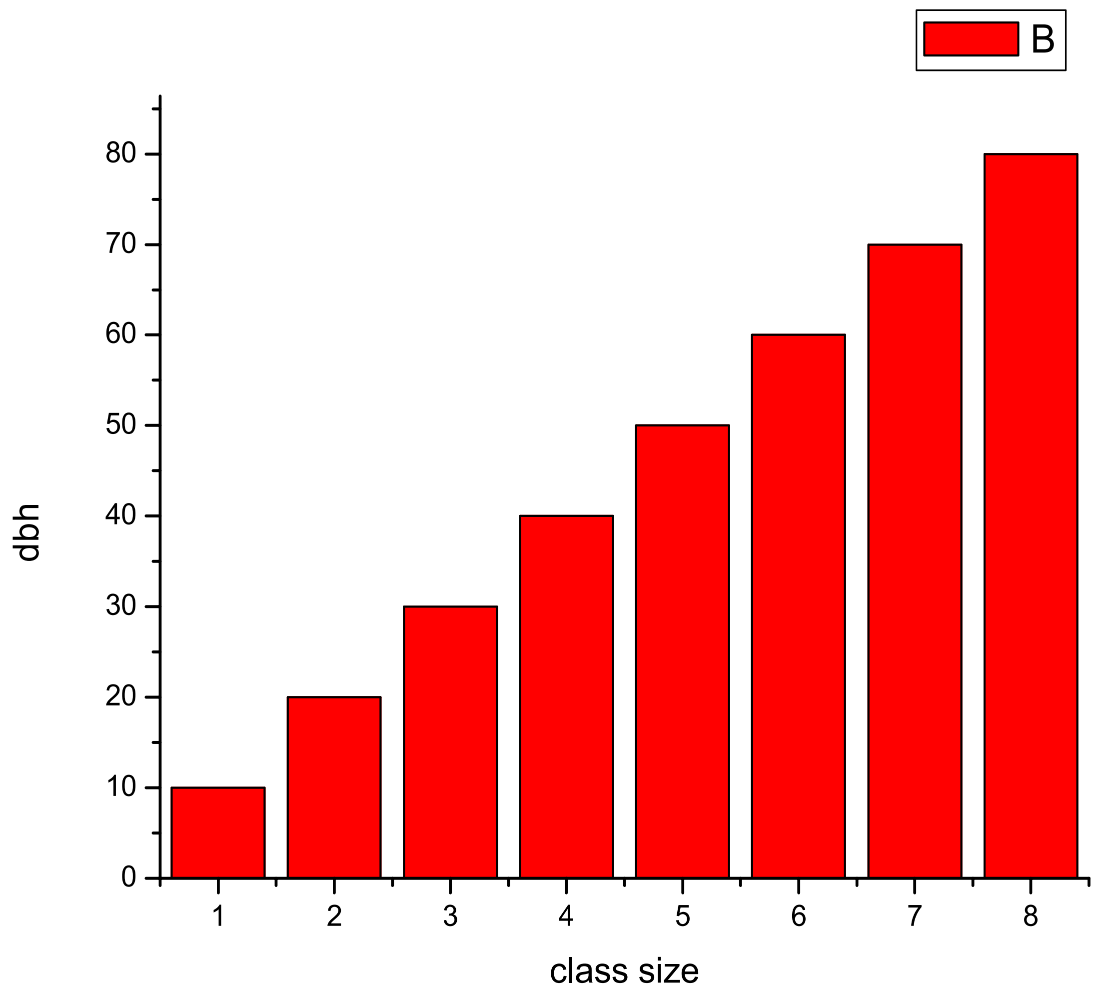
$$Ht = \text{Exp}\,(0.58048 + 0.602965 * \text{Ln}\,(DBH))\ (R2 = 83,\ SE = 1.32,\ N = 132)$$

Where Ht is total tree height in meters; DBH is tree diameter at breast height; Ln is the natural logarithm; R2 is the coefficient of determination, SE is the standard error of estimate and N is the number of observations.
Basic stand parameters including stand density in terms of number of stems per ha (N), basal area (G, m^2/ha) and volume (V, m^3/ha) were calculated using standard mensuration formulae. Single tree volumes were estimated using the equation developed by Malimbwi et al. (1994):

$V_i = 0.0001 d_i^{2.032} h_i^{0.66}$

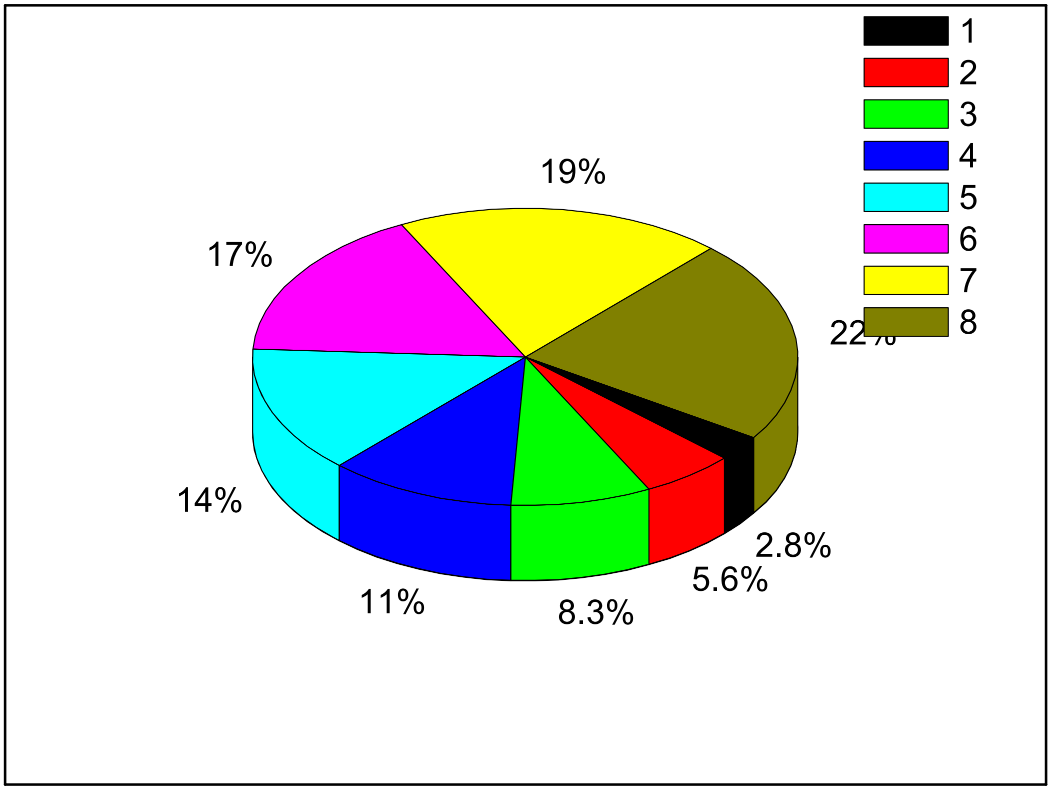
Where Vi is the volume (m^3) of the *i*th tree with DBH di (cm) and total height, hi (m). Furthermore, all computed parameters were clustered into eight size classes as follows:

Size class	DBH range (cm)
1	1 – 10
2	11 -20
3	21 -30
4	31 -40
5	41 -50
6	51 -60
7	61 -70
8	> 70.


B
dbh
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
class size

FREQUENCIES TEST . VAR00002

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10	1	11.1	11.1	11.1
	20	1	11.1	11.1	22.2
	30	1	11.1	11.1	33.3
	40	1	11.1	11.1	44.4
	50	1	11.1	11.1	55.6
	60	1	11.1	11.1	66.7
	70	1	11.1	11.1	77.8
	80	1	11.1	11.1	88.9
	dbh	1	11.1	11.1	100.0
	Total	9	100.0	100.0	



PIE- CHART OF CLASS SIZE AND DBH SAMPLE TREE.

Herbs and grasses were not analyzed quantitatively in this research. However, the information on presence or absence of herbs and grasses and their different types or species has served as a basis for assessing qualitatively the extent of soil and land degradation under the forest.

Socio-economic data was obtained from the studies by Otieno (2000) and Kajembe et al. (2003) which used Participatory Rural Appraisal (PRA) techniques. The PRA group included elders, middle-aged, youth and village government leaders. Methods used in the PRA include, among others, participatory mapping and modeling, historical trends, chapatti (or Venn) diagrams for institutional analysis, direct matrix and pair wise ranking and scoring for problem analysis.

Checklists were used to collect information from key informants including village leaders, village elders (men and women), village executive officers and village environmental committee members.

Data collected through PRA techniques were analyzed with the help of the local communities in the PRA groups. Other data were analyzed through content and structural-functional analyses.

At Abuko Forest Reserve, most of the data was collected by the Gambia Collaborative Research Centre,which is part of the International Forestry Resources and Institutions research programme. The data falls into two parts in accordance with International Forestry Resources and Institutions protocols (Ostrom 1998). One part includes data about social attributes while the other comprises of data about forest attributes. Data collection took place during two field visits in July 2011 and November 2011.

Data on socio-economic attributes was collected using PRA methodologies, group discussions and individual interviews with local officials. The local officials interviewed included a forester in charge of the forest reserve and three leaders of non-harvesting organizations. Secondary data was obtained at the village and regional level offices.

During forest inventory, the forest reserve was stratified – 15 plots were located in the Abuko vegetation and 15 plots in the lowland forest. The researcher applied both systematic and random sampling designs. Starting with a randomly selected plot, the remaining plots were systematically selected, but randomly numbered. After selecting the first plot the location of all other plots in the forest was selected by walking 50m along the transect and turning 90º either right or left, at which point the plot was located 15m from the transect. The directions were alternated after each plot.

Once the centre of a plot was located, three concentric circles were marked. In the 1m radius sub-plot, data was collected on all herbaceous ground cover and seedlings with a diameter of less than 2.5cm. In the middle circle (3m radius) all shrubs and trees were identified, their DBH measured and their heights estimated. Within the 10m radius, only trees with DBH greater than 10cm were measured.

Since the forest was first visited in July, the collection of socio-economic and forest data on the November revisit allowed both qualitative and quantitative comparison of management impacts for the Five -month period. Qualitative data of July and November was analyzed by content analysis, while the quantitative socio-economic data was analyzed by descriptive statistical methods (means, standard errors and so forth) and cross tabulation (contingency tables). PRA data was analyzed with the help of the local people. From the forest inventory data, stand parameters (density, basal area and volume per ha) were estimated and compared for July and November using cross tabulation. A student t-test was used to compare the basal areas and the density of saplings and mature trees.

The logistic regression model, as a member of General Linear Models (GLM), is for categorical response variables. In general, the logistic model transforms the categorical response variables into logarithmic forms, which makes the forms of the coefficients of the explanatory variables consistent with other linear models. The general form of the logistic regression model

is: $\text{logit}[\theta(x)] = ά + \beta 1\, x1 + \beta 2\, x2 + \cdots + \beta n\, xn$ (1)

The S-shaped curve in Figure 2 describes the shape of the logistic function. The X-axis is for explanatory variables and the Y-axis represents the probability of a response category given the values of the explanatory variables. There are three types of logistic regression, which depend on the type of categorical response variable: binary (or binomial) logistic regression, multinomial logistic regression, and ordinal logistic regression. The binary logistic model is used in this research and is applicable when the response variable is dichotomous and the explanatory variables are of any type. When categorical response variables have more than two classifications, multinomial logistic regression is used. Ordinal logistic regression is preferred to multinomial logistic regression when the categories of the response variable can be ranked from “low” to “high.”

Logistic models have some advantages such as having no stringent assumptions about the explanatory variables. Logistic models do not require a linear relationship between the explanatory variables and the response variables. Moreover, logistic models do not have the stringent assumptions of normally distributed variables or homoscedasticity of the residuals.

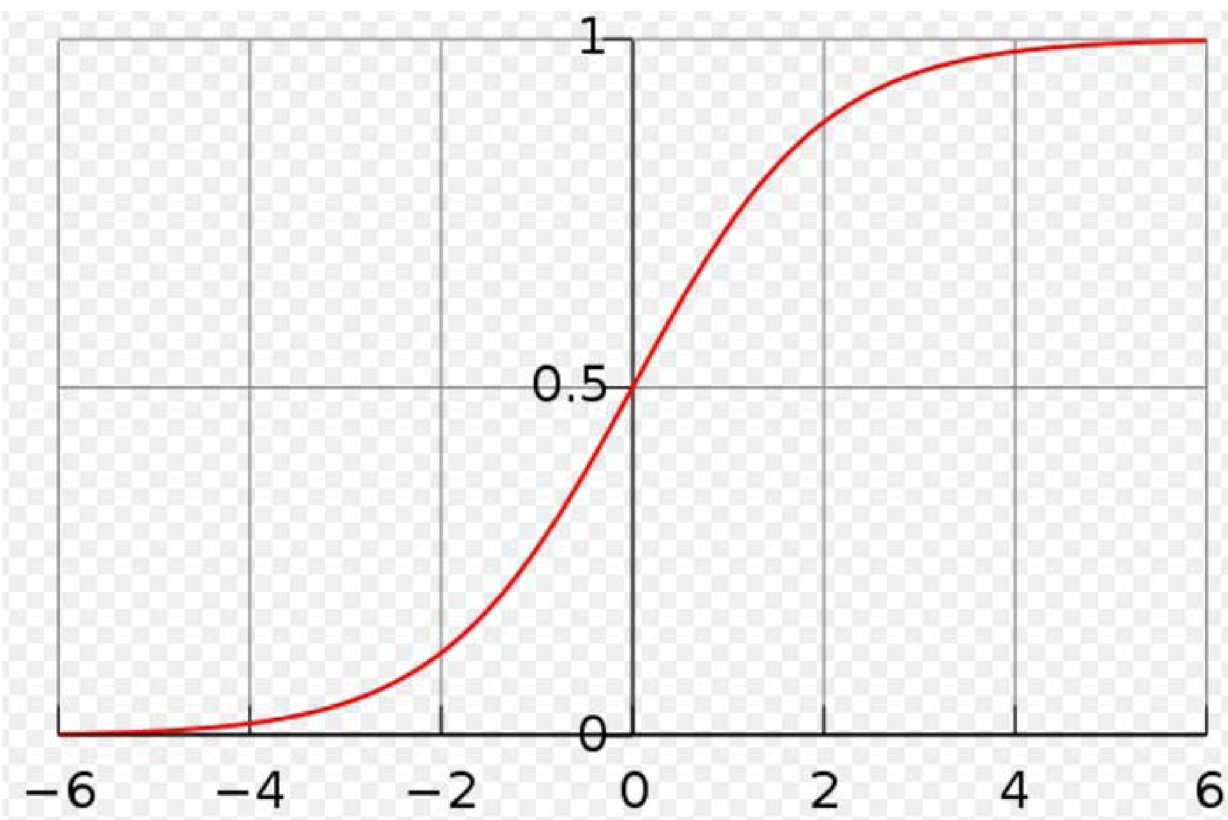


FIGURE 4.2- Standard logistic regression curve (Gershenfeld ,1999).

Classification tables are used to examine the predictive success of a logistic regression model. Lift charts can be used to show the same information as the "Receiver Operating Characteristic" (ROC) curves to assess model fitness. Goodness-of-fit tests, such as the likelihood ratio test, are another way to test the appropriateness of the model. Wald statistics are used to test the significance of individual explanatory variables.

Belgian mathematician Pierre Francois Verhulst first developed the logistic model in 1838 (Cramer 2003). Verhulst suggested that population growth rates have limitations, for example, the rate may depend on population density. The equation is:

$$r = ro\left(1 - \frac{N(t)}{k}\right)$$

In this equation, the function N(t) represents the number of individuals at time t; the constant ro represents the population growth rate in the absence of intra-specific competition; and k is the carrying capacity, or the maximum number of individuals the environment supports. At low densities(N<<0, the population growth rate r, is maximal and equals ro. Population growth rates decline to 0 when N(t) =k. If N(t) >k, the population growth rate becomes negative.
The solution of this model is:

$$N(t) = \frac{No\,k}{(No + k - No)e^{-rot}}$$

After Verhulst, physiologist T., Brailsford Robertson in 1908 applied the sigmoidal curve to individual growth in animals, plants, and man in two articles (Kingsland 1985). Robertson called his curve the "autocatalytic" curve or the self-accelerating curve when referring to only the accelerating part of the curve.
Pearl and Reed (1920) criticized Robertson's theory and reached the curve in Figure4. 2.
Throughout the next twenty years, Pearl and his collaborators applied the logistic growth curve to almost all living populations and used it widely and indiscriminately during their career development. Yule's presidential address (Yule 1925) to the Royal Statistical Society of 1925 was an important publication for logistic model development and he was the person who named the model as logistic. By 1924, "logistic" had become a common word in the correspondence between Pearl and Yule (Cramer 2003). Reed and Berkson (1929) applied logistic models to analyzing autocatalytic reactions in chemistry.

Reed and Berkson's work marked another early study of the applications of the logistic model.
Two study groups were generated for the logistic regression models developed in the research. Locations that have an existing wood-using facility are coded as "1" in the data set for the logistic models. The two biomass-using facilities groups were:

1) All wood-using mills with wood-using bioenergy and biofuels plants;
2) Pulp and paper mills with wood-using bioenergy and biofuels plants.

Group I biomass-using facilities include primary wood processing mills, secondary wood processing mills, pulp and paper mills, and other mills. As defined by Perlack et al. (2005), primary wood processing mills convert roundwood into other products. These wood processing mills include sawmills, medium density fiberboard (MDF), oriented strand board (OSB), particleboard, plywood, veneer post, pole, piling, dealer, yard, energy and wood chips.
Secondary mills in Group I are mills that utilize the products of primary mills. Examples of secondary wood processing mill products include millwork, containers and pallets, buildings, furniture, flooring, paper and paper products. Secondary wood processing mills in this research not only include the above products, but also include planed wood products, remanufactured wood products, pallets, boxes, cabinets, trusses, mouldings, kiln dried products, treated wood products, Definitions of primary mill, second mill, pulp and paper mill are from Perlack et al. (2005). plants, decking and siding. Other mills include forestry companies, logging mills, and companies that provide equipment and supplies, such as logging machine rental companies.

Pulp and paper mills are included in Group I biomass-using facilities, too. Wood-using bioenergy and biofuels plants (also called "biorefineries") are defined in this analysis as facilities that use all possible wood residues in an integrated biomass conversion process to produce biofuels, biopower, or biochemicals (National Renewable Energy Laboratory 2009)
Greater Banjul region, west coast region, and North Bank region have the smallest quantity of mills compared to the large volume of mills in the other region. There is a high concentration of mills in the Greater Banjul region relative to the other region in this group. Some region are not suitable locations to build woody biomass-using facilities because of their geographic and/or economic characteristics.

For example, if a region has no land, no living trees, or is in a big city, this region is regarded as a "non-probable" location for the woody biomass-using facilities, and we code the response in this region as "0". Specifically, three variables in Table-1 are used to define "non-probable" locations. A region is regarded as a "non-probable" location if Sqmiland = 0 (i.e., it has no land and may be

Table 1 -Three variables for specifying "non-probable" locations of all wood-using mills with bioenergy and biofuels plants.

Variable name	Variable type	Collection level	Explanation
sqmiland	continuous	Greater Banjul	Land area (mile2)
Dry_bio_tot	continuous	North bank region	Total standing volume in dry tons of all inventory species (trees >= 1.0 inches d.b.h3.) on forestland (Perlack et al. 2005).
Metropolitan	Binary	City	Metropolitan or not ("1" for metropolitan area and "0" for not)

water, parks, or buildings), DRY_BIO_TOT = 0 (i.e., it has no living trees), or Metropolitan = 1 (i.e., it is in a metropolitan area).

Table-2

EXPLANATORY VARIABLES FOR TWO-GROUP OF BIOMASS –USING FACILITIES.

Variable name	Variable type	Unit	explanation
employment	continuous	People	Employed person in all industries.
population	continuous	People	Population in each region.
Population density	;;	People	Population density
Median family income	;	GMD	Median of family income in 2005
Income index		GMD/people	Median family income per employed person.
Log-res-hw		Dry Tons	Logging residues of hardwood, logging residues of softwood and the total of both logging
Log-res-sw		;dry Tons	Residues are the unused portion of growing stock trees cut .
Log-res-tot		;dry Tons	Killed by logging and left in the wood.(per lacks et al 2005)
Other-rem-hw	continuous	Dry Tons	Other removal of hardwood, other removal of softwood and the total of both.
Other-rem-sw			Other removal is the unutilized wood volume from cut or otherwise

			killed growing stock, from cultural operation's such as precommercial thinning or from timber land clearing.
Other-rem-tot			Does not include volume removed from inventory through reclassification of timberland to productive reserved forestland.

This research work reviews an aerial sampling technique that could reduce the cost of calculating standing forest biomass in remote regions by collecting a geographically distributed set of large scale transects that include a limited number of permanent plots. The biomass of these plots is calculated from allometric equations and extrapolated to the transects as a function of tree species, crown diameter and height. Two kinds of aerial imagery sampling techniques were tested over a mixed hardwood /closed forest in Gambia. Thirty- 28-meter diameter plot sites were established along two transects within the test site and the dbh (diameter at breast height) of trees measured. Each transect was flown at 4,000 feet AGL with a small format photogrammetric camera, then at 1,000 feet AGL with global positioning system (GPS)-logged dual-camera video (wide-angle/zoom), and a profiling laser. The photogrammetric images were used to create 3D models of the terrain from which average tree heights and forest volumes could be calculated. The video / laser coverage was used to visually identify the species of individual trees, measure their crown diameters in a 2D geographic information system (GIS) and estimating their heights from the laser profile.

Due partly to an automatic georeference and mosaicking program developed for the video coverage during the research, it proved the more accurate / cost effective approach and this research work concentrates on its results. Average dbh values of one hectare transect calculated from the video are compared to those measured on site, showing a strong positive correlation given the small sample size.

The 1997 UN Convention on Climate Change in Gambia established a framework for assigning economic value to carbon sequestered in biomass. This could benefit efforts to preserve tropical forests in Gambia if their carbon content can be accurately measured and monitored. Field methods with extensive permanent plots can estimate biomass in a forest to known levels of precision, but these plots are expensive to reach and maintain in isolated areas. The resulting costs that can vary from approximately GMD50.00 to GMD100.00 per ton depending on inventory frequency, accessibility, spatial variability of carbon pools, labor costs and scale, making the process least practical in some of the areas most worthy of preservation.

The use of forest wastes for the production of bioenergy and liquid biofuels has potential to offset the use of fossil energy sources. Some studies suggest biofuel and bioenergy produced from the removal of forest waste − products considered to be uneconomical to harvest generates significant well to- tank greenhouse gas (GHG) emission savings by displacing energy produced from fossil resources. In parallel, an increase in the frequency and intensity of wildfire both empirically observed and predicted by climate change models has highlighted the need to actively manage forests to increase the resilience of forests to wildfire. Integrated analysis that takes into account the dynamic interactions between carbon (C) pools resulting from forest management practices, forest fire behavior, and the fate of forest biomass in debris, forest products, and energy production will provide a consistent framework for policy planning that maximize the overall benefits of GHG policy. This integrated approach will have a better chance of balancing the tradeoffs and maximizing synergies between C management and sustainability goals. This research work outlines a lifecycle accounting framework for evaluating the GHG benefits of utilizing forest biomass for bio-energy production under various forest management strategies.

In this research, interviews were conducted with public and private landowners, biomass fuel processors and suppliers, and biomass fuel consumers within the study resource areas. Information from a variety of industry sources, including the Coca-cola industries, Gambia cement industry, Gambia Forestry department , the National Renewable Energy Agency of the Gambia ,Gambia Department of Energy, the Gambia Department of Geology, the Gambia Department of Natural Resources, Gambia graphical information services (GIS), third-party consultants, and local news media sources were obtained and analyzed.
The researcher made the following assumptions in accordance with performing the analyses for this research and developing conclusions:

1. Woody biomass would be the sole fuel source for the biomass facility.

2. The facility would consume approximately 4,000BDT of woody biomass annually.

3. The site for the proposed woody biomass facility (Site) would be located on Lower River & North Bank Regions of the Gambia.

4. The potential resource areas for available fuel covers everything within a 90 minute haul-time of the Site, and the six region that make up a majority of the public and private commercial timberlands within the Study Resource Area:

5. The forecasted long-term current average and inflation-adjusted price for forest residual biomass hog fuel within the study resource areas cannot exceed GMD45 per BDT in order for the facility to be economically viable and feasible.

6. All information and data collected by or provided to the researcher in conducting this study are true, accurate, and complete.

Figure 4. 3- [a] logged wood from forest.

Understanding the carbon storage of the biosphere is important for its role in the global carbon cycle, and the need to predict biomass and primary productivity patterns has not lost its urgency since the pioneering work of Lieth (1972). Studies of regional vegetation patterns reveal that vegetation types may be sensitive to temperature changes as little as one degree (Box et al. 1999; Hilbert et al. 2001; Hilbert & Ostendorf 2001; Iverson et al. 1999). The ability to measure carbon exchange rates with the atmosphere has been substantially improved, but what actually determines the spatial pattern of biomass is still not understood. Tropical regions are receiving increased attention due to their importance in the global carbon cycle (Justice et al. 2001; Nascimento & Laurance 2002). Assessment of the future state of the biosphere, including biomass, productivity and biodiversity, however, ultimately relies on field data, and these are difficult to collect because of spatial and temporal variability (e.g. Ostendorf et al. 2001a). This is particularly evident for tropical systems where remoteness and climate-related logistical difficulties add to the problem. A low number of objectively selected field locations often prohibits a regional analysis of environmental gradients. Brown & Lugo (1984) illustrated the difficulties in obtaining statistically sound biomass data and concluded that earlier estimates of the carbon content of tropical vegetation based on destructive sampling were biased toward more productive plots.

Understanding the causes of observable patterns will improve spatial sampling designs for future field studies and indicate the relative importance of spatial surrogates, which may be used to interpolate and possibly extrapolate field data. The tropical region of Gambia provides a unique natural laboratory for several reasons. It exhibits steep climatic gradients with annual precipitation of up to 800 mm, gradients of more than 30 mm per km, and mean annual temperature ranges from 16 to 25°C. A large variety of different tropical and subtropical forest types (see Webb et al. 1959, 1968) occurs in close proximity. Furthermore, the Gondwanan Ostendorf, Bradford & Hilbert origin and richness of endemic species and the region's past economic potential for wood production and agriculture provide for a long history of ecological research at a regional scale. The boundary between rainforest and woodlands (sclerophyll forest types1) has been of particular interest for land managers and ecologists in various tropical and subtropical regions. In Gambia, this region provides habitat for several rare and endangered mammal and bird species (Winter et al. 1984). Since this boundary constitutes an ecotone, climate change may affect this vegetation belt most strongly (Hilbert et al. 2001; Hilbert & Ostendorf 2001). Ostendorf et al. (2001b) assessed the sensitivity of the model predictions to changes in model structure (including different spatial and ecological constraints on vegetation change) and found that vegetation types at the rainforest boundary are least predictable. Regional management and ecosystem conservation is challenging because of the substantial knowledge gaps of the forests sensitivity to climate change, especially if one considers a possible increase of mean annual temperature by 2-4°C during the next 10 years (Walsh et al. 2000). A comprehensive survey of forest structure was undertaken (Harrington et al. 2000) in the "Wet Tropics" region of Gambia between roughly –15 and –20° latitude. Basal area was recorded for all trees with a DBH >= 2 cm on a total of 237, 20x20 m plots at the rainforest boundary. A comprehensive set of site attributes was collected at each plot. Furthermore, vegetation was mapped using air photos and a regional classification of different rainforest types. The small plot size was a compromise to obtain regionally representative tree population information. In parallel, a comprehensive GIS was developed including a detailed digital terrain model (DTM), surfaces of climate and topographic variables and soil parent material. In this research, a regional analysis of biomass in the rainforest region is presented and a statistical analysis of biomass and environmental conditions as represented by a set of 6 maps of environmental conditions and local plot descriptions was conducted. This allows a ranking of relative predictive capability of forest biomass for a comprehensive set of environmental variables.

4.2 QUANTITATIVE DATA ANALYSIS.

This analysis was undertaken to evaluate the forest land base suitable for sustainable extraction of forest biomass and to estimate low-quality wood biomass production for the study areas defined by regional boundaries—the six regions of the Gambia consisting of Greater Banjul, western region ,lower river region,upper river region ,North bank region and Central river region. Within this research work the adjective 'suitable' is used to denote the land base of currently forested lands that have met the sustainability filter that the modeling employed and are legally available for timber extraction.

Increases in the use of fuel wood, be it in the form of chips, split logs, or pellets, have been accompanied by increased concern that wood biomass harvest be conducted sustainably (Evans and Perschel 2009).

Sustainable harvest of forest products includes matters of where, when, how, and how much is taken from a forest area. This research work evaluated the 'where' of sustainable harvest by applying GIS modeling to exclude areas considered to be unsuitable for tree harvest based on site characteristics such as soils, slopes, elevation, surface waters, wetlands, and conservation protections. After calculating the suitable forest land bases, growth estimates were utilized from previously published models to estimate broad ranges of 'how much' low-quality wood could be sustainably extracted annually.

As every person who works with land and resources knows, each site and landscape has its own unique conditions, which include geophysical and ecological characteristics as well as human values related to forests and lands.

This analysis is a landscape-level modeling exercise, and although, maps are generated to depict the two forest land bases suitable for sustainable tree harvest, these maps were not intended to be used at the site level for forest management planning. Nevertheless, in presenting a set of criteria to use in assessing which forestlands are suitable for sustainable biomass extraction, this analysis may be thought of as a starting point for evaluating individual sites. On-the-ground investigation of site and stand conditions would be required to accurately map the landscape and to fully evaluate the capabilities of any given forest tract.

On a theoretical note, many have pondered and written about sustainable use and management of forests. It is not my intent here to defend any one view of sustainability, but it is useful to state some of my fundamental assumptions and some documented information about Gambia forests. Foremost, I believe that sustainability is a goal to strive for, and as human knowledge and understanding of earth and its natural systems continue into the future, ideas about what actually constitutes sustainability will change.

The present analysis is one moment in a long path. Moving from theory to the actual land, I acknowledge that the forest ecosystems that presently occur in the Gambia landscape are much changed from those that existed prior to forest harvest and clearing by peoples of other Africa nations. The current forests have quite different stand composition (Cogbill 2000, Cogbill et al. 2002) as well as stand structure (Tyrell and Crow 1994, Woods 2000, Lorimer et al. 2001, Schwarz et al. 2001, Lapin 2005). Ecologists have shown that the current forests are composed of trees with a younger average age and a smaller average size, as well as lower live-tree biomass. These forests also have a reduced biomass of woody debris, the storehouse of moisture and nutrients and provider of habitats for many organisms (Harmon et al. 1986). The point here is that if I take the current forest structure as a starting point of 'what happens' in Gambia forests, I will be skewing my perspective from the outset. Growth rate is correlated to structure, and structure at any given time obviously depends to a great extent on past occurrences (human activities and natural disturbances) and growth rates. The present analysis makes no assumption that maintaining the structure that the forests currently exhibit is a basic building block of sustainable forest management.

The current forests on the specific landscapes that are the subject of this analysis are very clear, still recovering from the well-documented uses and abuses of the past two centuries. Hence, analyses that document that tree biomass is growing at a rate substantially greater than the rate at which it is harvested, say little about long-term sustainability. One must question the baseline to fully explore the matter of sustainability. Are we as a society satisfied with maintaining forest ecosystems that have younger and smaller trees than those that grew when our forefathers felled the forests? How do we balance that question with our need to wean ourselves from the fossil-fuel addiction?

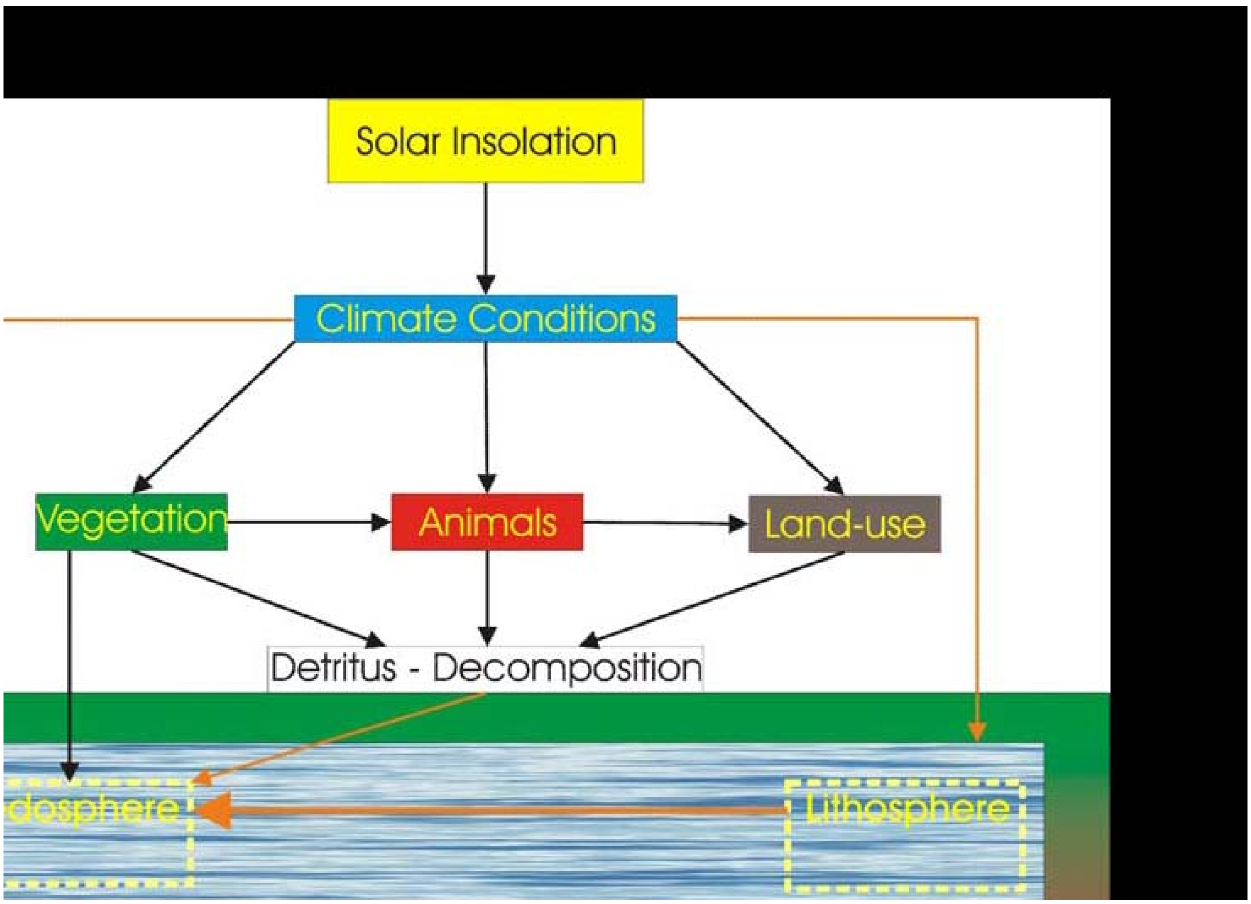


FIGURE 4. 4 -Ecological Divisions of the Geosphere.

4.2.1 Crop residues

The following crops are included in this analysis: corn, wheat, soybeans, sorghum, barley, oats, rice, beans, peas, peanuts, potatoes, sunflower, and flaxseed. The quantities of crop residues that can be available in each region were estimated using total grain production, crop to residue ratio, moisture content, and taking into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities. All estimates were developed using total grain production by region for 2005 reported to the Gambia Ministry of Agriculture. Quantities that must remain on the field for erosion control differ by crop type, soil type, weather conditions, and the tillage system used. It was assumed that 30% residue cover is reasonable for soil protection. Animals seldom consume more than 20%-25% of the stover in grazing, and i presume about 10%-15% of the crop residue is used for other purposes: bedding, silage, etc. Therefore, it was assumed that about 35% of the total residue could be collected as biomass.

Depending on the units in which the crop production is reported the following equations were used:

For crops reported in pounds (beans, peas, peanuts, rice, potatoes ,and sunflower): BDT residue = crop production * crop to residue ratio * Dry Matter % / 2205

For crops reported in BU (barley, corn, oats, sorghum, soybeans, wheat, and flaxseed):

BDT residue = crop production * crop to residue ratio * Dry Matter % / K

For crops reported in short (US) tons (sugar cane):

BDT residue = crop production * crop to residue ratio * Dry Matter 0.9072

Where:

BDT – Bone dry tonnes

BU - Bushel

1 metric ton (MT) = 2205 pounds

K - BU to MT conversion or 2205 / Bushel weight (in Lbs)

0.9072 – conversion from short (US) tons to metric tons

Table -3: Crop to Residue Ratio and Moisture Content of Selected Crops

CROPS	Ratio of Residue to Crop Volume*	Moisture Content (Percent)**	Bushel Weight (lb)***
Barley	1.2	14.5	48
Corn	1.0	15.5	56
Dry Beans	1.2	13.0	60
Peanuts	1.0	9.9	22
Rice	1.4	15.0	44
Groundnuts	1.5	9.8	60

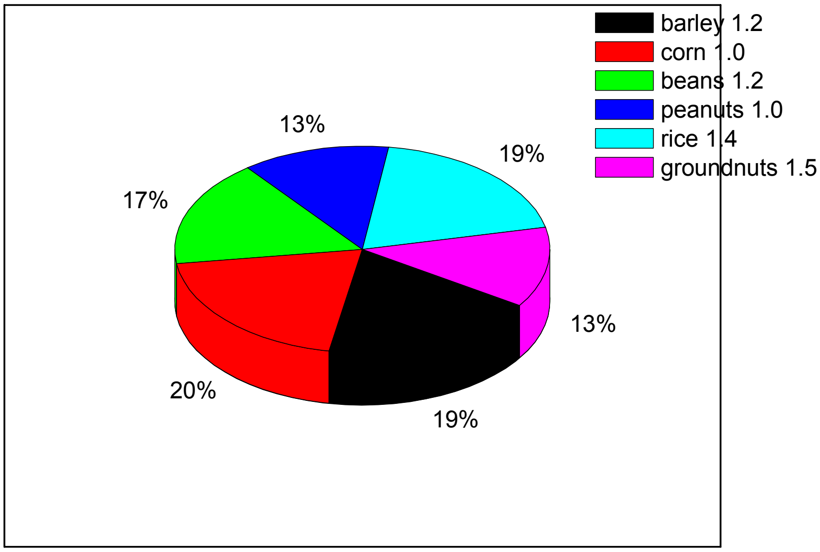
Independent t-Test on Data1 col(A) and col(B) For Table 3

Data	Mean	Variance	N
A	--	0	0
B	12.95	6.467	6

t = --

p = --

At the 0.05 level, the two means are significantly different.



PIE-CHART OF CROP RESIDUE & MOISTURE CONTENT

Polynomial Regression for Data1_A:

Y = A + B1*X + B2*X^2

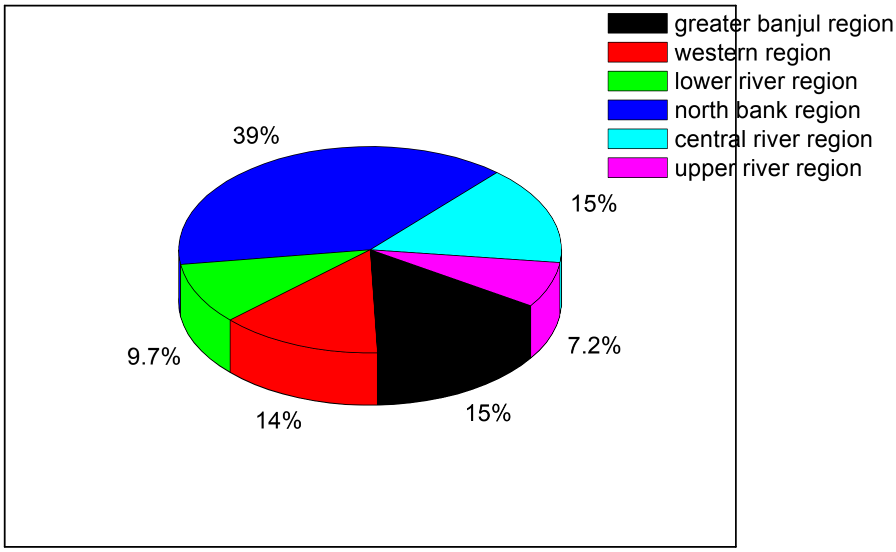
Parameter	Value	Error
A	15.66	4.73856
B1	-0.72786	3.10009
B2	-0.01071	0.43353

R-Square(COD)	SD	N	P
0.34898	2.64894	6	0.5252

Fit and Residual data have been saved into Data1 worksheet.

Table—4 Estimated Crop Residues by Region

Regions.	Crop Residues (Thousand Dry Tonnes)
Greater Banjul region (2)	391
Western region (4)	351
Lower river region (6)	248
North Bank region (8)	997
Central river region (10)	396
Upper river region (12)	185



PIE-CHART OF CROP RESIDUES BY REGION IN THE GAMBIA.

Independent t-Test on Data1 col(A) and col(B):

Data	Mean	Variance	N
A	--	0	0
B	428	84706.4	6

t = --

p = --

At the 0.05 level, the two means are significantly different.

Polynomial Regression for Data1_A:

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	-31.9	590.35313
B1	351.70357	386.22515
B2	-50.83929	54.01178

R-Square(COD)	SD	N	P
0.22855	330.01743	6	0.67758

4.2.4 Methane Emissions from Manure Management

In manure management systems, methane is produced by the anaerobic decomposition of organic matter. The type of manure management system employed determines the extent to which this process occurs. Types of systems included in the EPA State Workbook are pastures, deep pits, liquid slurry, and anaerobic lagoons. Generally speaking, liquid manure management systems, such as ponds, anaerobic lagoons, and holding tanks promote methane production. Manure deposited on fields and pastures, or otherwise handled in a dry form, produces insignificant amounts of methane.

For the purpose of this analysis, the following animal types: dairy cows, beef cows, hogs and pigs, sheep, chickens (layers and broilers), and turkey were included The data on animal population by region was obtained from the 2002 Gambia Agricultural Statistics. All emissions were calculated by animal type and manure management system. The results of these calculations are shown in Table 5 with estimates summarized by region

The following steps were used to calculate methane emissions from manure management systems, based on EPA State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Second Edition, 1995, Workbook 7 Methane Emissions from Manure Management.

Determining the amount of volatile solids (VS) produced by each animal type.

The following equation was used to calculate pounds of volatile solids produced by each animal type:

Equation 1:

VSi produced per animal type = Animal population (head) * TAMi * vsi

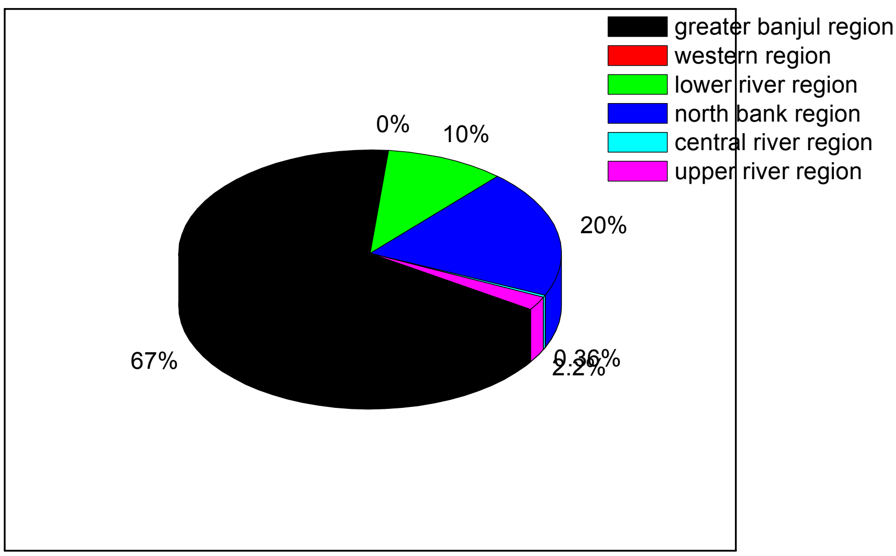
Where:

VSi..=Total VS produced (lbs./yr.) for animal type i TAMi.....=..Typical animal mass for animal type i (lbs./head) (VSi.....=..Average annual volatile solids production per unit of animal mass of animal type i (VS per pound of animal mass)

Table –5 Estimated Methane Emissions from Manure Management by Regions.

Regions.	Methane (Thousand Tonnes
Greater Banjul region (2)	94
Western region (4)	0
Lower river region (6)	14
North bank region (8)	28
Central river region (10)	0.5
Upper river region (12)	3

PIE –CHART FOR METHANE EMISSIONS FRON MANURE MANAGEMENT BY REGIONS OF THE GAMBIA.



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Polynomial Regression for Data1_A:
Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	119.95	52.96455
B1	-52.11964	34.65086
B2	5.65179	4.84576

R-Square(COD)	SD	N	P
0.60043	29.60808	6	0.25257

Independent t-Test on Data1 col(A) and col(B):

Data	Mean	Variance	N
A	--	0	0
B	23.25	1316.375	6

t = --
p = --

At the 0.05 level,
the two means are significantly different.

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Linear Regression for Data1_B:
Y = A + B * X

Parameter	Value	Error	t-Value	Prob>|t|
A	67.2	28.77839	2.33509	0.07981
B	-12.55714	7.38961	-1.6993	0.16449

R	R-Square(COD)	Adj. R-Square	Root-MSE(SD)	N
-0.64749	0.41925	0.27406	30.91295	6

ANOVA Table:

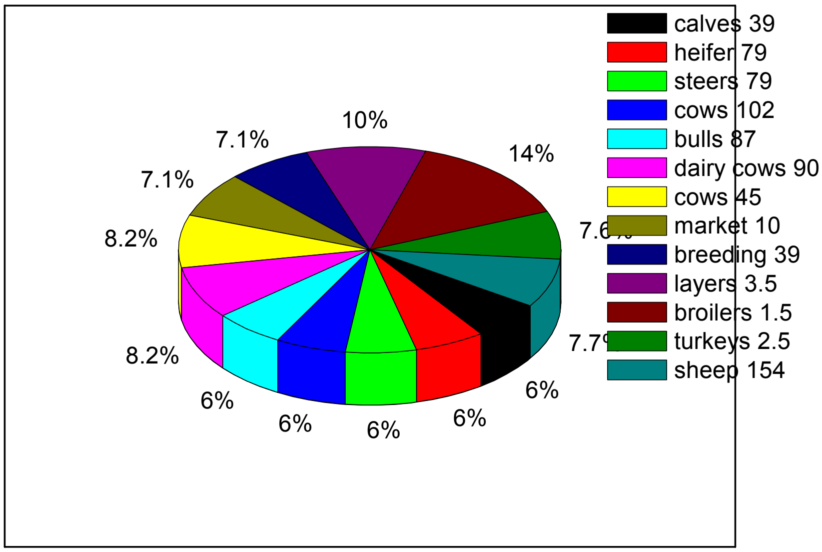
Item	Degrees of Freedom	Sum of Squares	Mean Square	F Statistic
Model	1	2759.43214	2759.43214	2.88761
Error	4	3822.44286	955.61071	
Total	5	6581.875		

Prob>F
0.16449

Table -6 Gambia Average Animal Size and vs Production

ANIMAL TYPE.		Typical Animal Mass (TAM) lbs	Volatile Solids (vs) lbs VS/ lb animal mass/yr
Beef cattle	calves	39	2.6
	Heifers	79	2.6
	Steers	79	2.6
	cows	102	2.6
	Bulls	87	2.6
Dairy cattle	Heifers	90	3.6
	cows	45	3.6
Swin	market	10	3.1
	Breeding	39	3.1
Poultry	Layers	3.5	4.4
	Broilers	1.5	6.2
	Turkeys	2.5	3.3
	Sheep	154	3.36

Note: Due to lack of separate data of market and breeding swine, the numbers for market swine were adopted .



PIE-CHART FOR ANIMAL SIZES AND THEIR PRODUCTIONS IN THE GAMBIA.

175

Independent t-Test on Data1 col(A) and col(B):

Data	Mean	Variance	N
A	--	0	0
B	3.35846	1.0241	13

t = --
p = --

At the 0.05 level,
the two means are significantly different.

Polynomial Regression for Data1_A:
Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	1.99007	0.86134
B1	0.26687	0.28297
B2	-0.00793	0.01967

R-Square(COD)	SD	N	P
0.36985	0.88	13	0.09936

Fit and Residual data have been saved into Data1 worksheet.

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4.2.5 Estimate the methane emission for each manure management system and animal type.

The solution of Equation 1, total amount of volatile solids, and additional data were then used in Equation 2 to calculate total methane emissions:

Equation 2:

CH4 emissions for animal i on system j (cu.ft./yr.)= VSi * Bi * MCFj * WS%ij

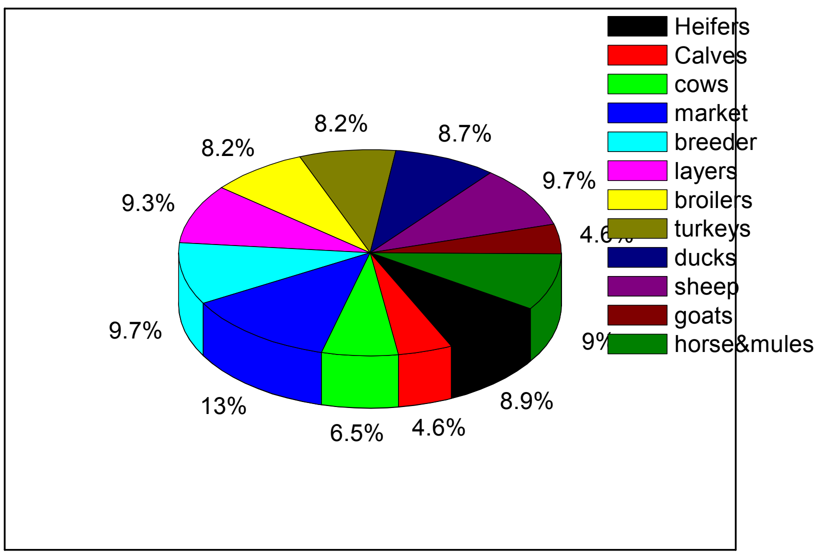
Where:

VSi .....=..Total VS produced (lbs./yr.) for animal type I (Equation 1) Bi.......=..Maximum methane producing capacity per pound of VS for animal type i (ft3/lbs. VS) (Table 5) MCFj.....=..Methane conversion factor for each manure system j (Table 5) WS%ij....=..Percent of animal type i's manure managed in manure system j (%) .

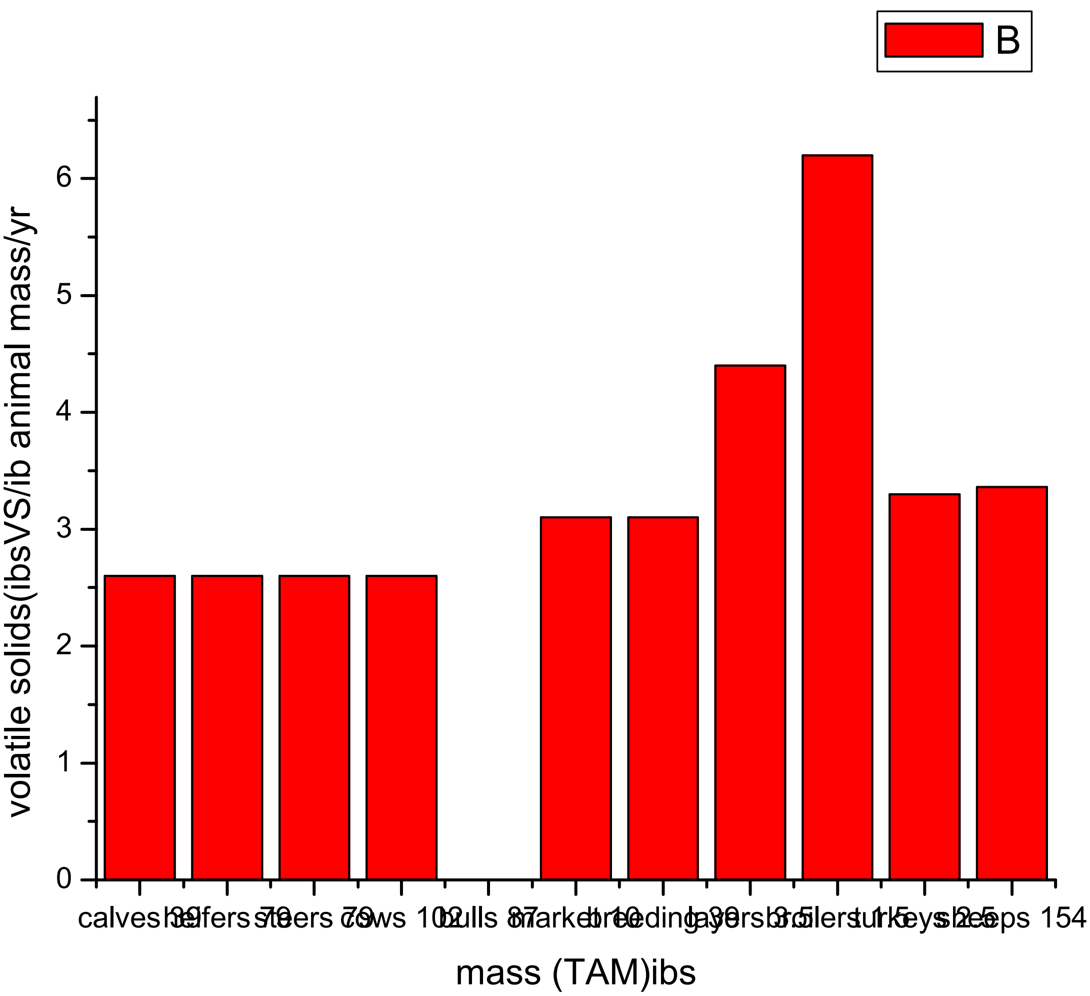
Table -7 Maximum Methane Producing Capacity Adopted For Gambia Estimates .

Animal Type,	Category	Maximum Potential Emissions (Bi)
Cattle	Heifers	5.2
	calves	2.7
	cows	3.8
Swin	market	7.5
	Breeder	5.7
Poultry	Layers	5.45

	Broilers	4.8
	Turkeys	4.8
	Ducks	5.1
	Sheep	5.7
	Goats	2.7
	Horses & mules	5.29



PIE-CHART OF METHANE EMMISSION CAPACITY IN GAMBIA


B
volatile solids(ibsVS/ib animal mass/yr
0
1
2
3
4
5
6
mass (TAM)ibs

179

Polynomial Regression for Data1 Table 7

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	3.73727	1.44145
B1	0.50279	0.50981
B2	-0.03896	0.03818

R-Square(COD)	SD	N	P
0.10381	1.39469	12	0.61065

Table -8 Methane Conversion Factors for Gambia Livestock Manure Systems*

Regions	Pasture, Range & Paddocks	Dry lot	Solid Storage	Daily Spread	Liquid/ Slurry
Greater Banjul	1.4%	1.9%	1.4%	0.4%	29.0%
Western region	1.2%	1.4%	1.2%	0.3%	21.9%
Lower river	1.5%	2.4%	1.5%	0.6%	28.6%
North Bank	1.1%	1.5%	1.2%	0.3%	23.8%
Central river	0.9%	1.0%	0.9%	0.2%	18.1%
Upper river	0.8%	0.8%	0.8%	0.2%	18.0%

Other Systems: Pit Storage for less than 30 days is assumed to have an MCF equal to 50% of the MCF for Liquid/Slurry. Pit Storage for more than 30 days is assumed to have an MCF equal to liquid/slurry. Anaerobic lagoons are assumed to have an MCF of 90%; litter and deep pit stacks an MCF of 10%.

Conversion of all units to tons of methane and summation of emissions over all manure management types.

CH_4 cu.ft./yr. * 0.0413 / 2205 0.0413 - Density of methane (lbs./cu.ft.) conversion factor to pounds 2205 – Pounds to metric tons .

WOOD RESIDUE

Forest Residues

Forest residue data in Gambia was derived from the Gambia department of Forest Service's Timber Product Output database for 2009. In this category, logging residues and other removals were included .Logging residues are the unused portions of trees cut, or killed by logging, and left in the woods. Other removals are considered trees cut or otherwise killed by cultural operations (e.g. pre-commercial thinning, weeding, etc.) or land clearings and forest uses that are not directly associated with round wood product harvests. It does not include volume removed from the inventory by reclassification of timberland to productive reserved forestland. The results of this analysis are visualized in Table 9 below.

Data on volume (cubic feet) of logging residues and other removal in Gambia was collected from the Timber Products Output Mapmaker version 1.0. Then the following volume conversion factor was used for computations .

1 mcf= 0.0125 MBDT where 1 mcf= 1000 ft 3 and 1 MBDT = 1000 bone dry tons

Table 9- Estimated Forest Residues by Region.

Region	Forest Residues (Thousand Dry Tonnes
Greater Banjul	89

Western region	72
Lower river	5
North Bank	134
Central river	59
Upper river	29

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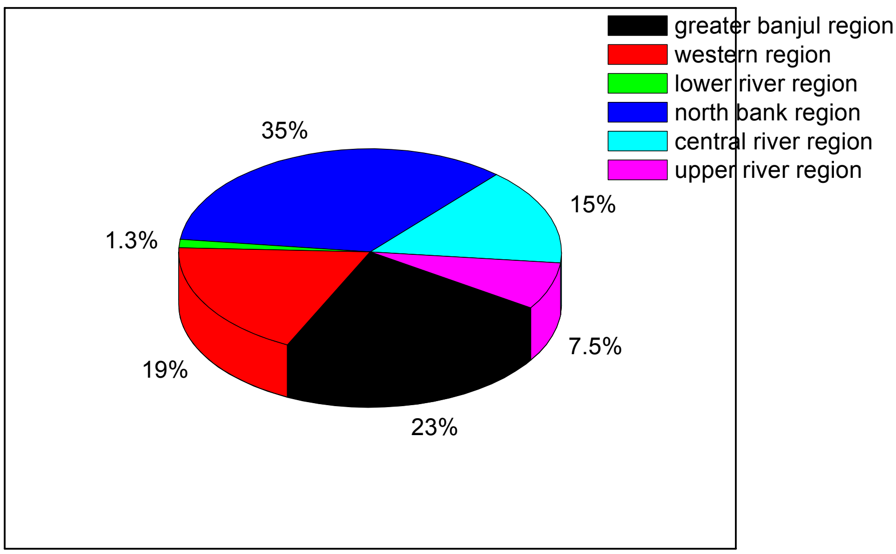
PIE-CHART OF FOREST RESIDUE BY REGION OF GAMBIA.



Independent t-Test on Data1 col(A) and col(B) for Table 9

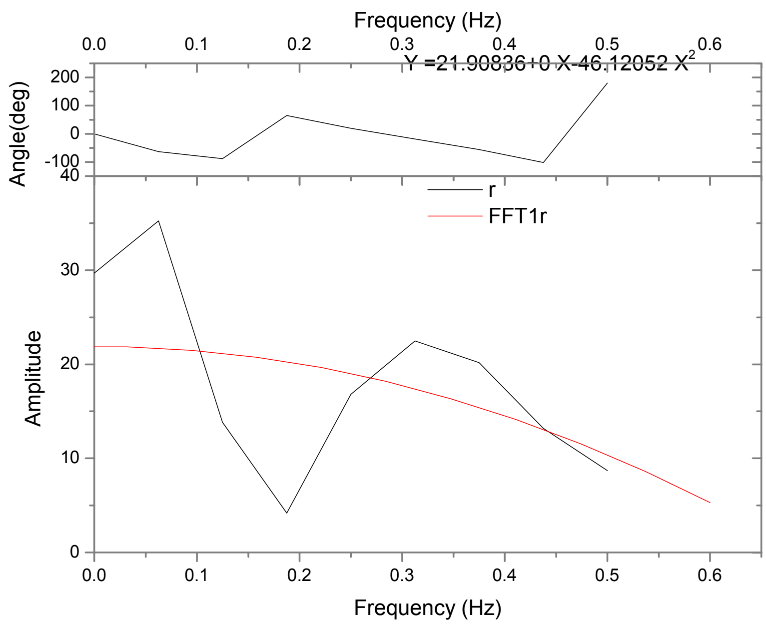
Data	Mean	Variance	N
A	--	0	0
B	64.66667	2063.46667	6

t = --

p = --

At the 0.05 level, the two means are significantly different.

183



Polynomial Regression for FFT1_R:
Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	21.90836	3.32945
B1	0	7.22819
B2	-46.12052	26.53215

R-Square(COD)	SD	N	P
0.17752	9.12514	17	0.25462

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Primary Mill Residues

Primary mill residue data in Gambia was derived from the Gambia Department of Forest Service's Timber Product Output database for 2009. Primary mill residues are composed of wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, like slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings. It includes mill residues recycled as byproducts as well as those left un-utilized and disposed of as waste .

Table 10- Estimated Primary Mill Residues by Region (Thousand Dry Tonnes)

Region	Total	Unused.
Greater Banjul	181	87
Western region	14	0.05

Lower river	109	0.2
North Bank	29	5
Central river	138	0.2
Upper river	57	9

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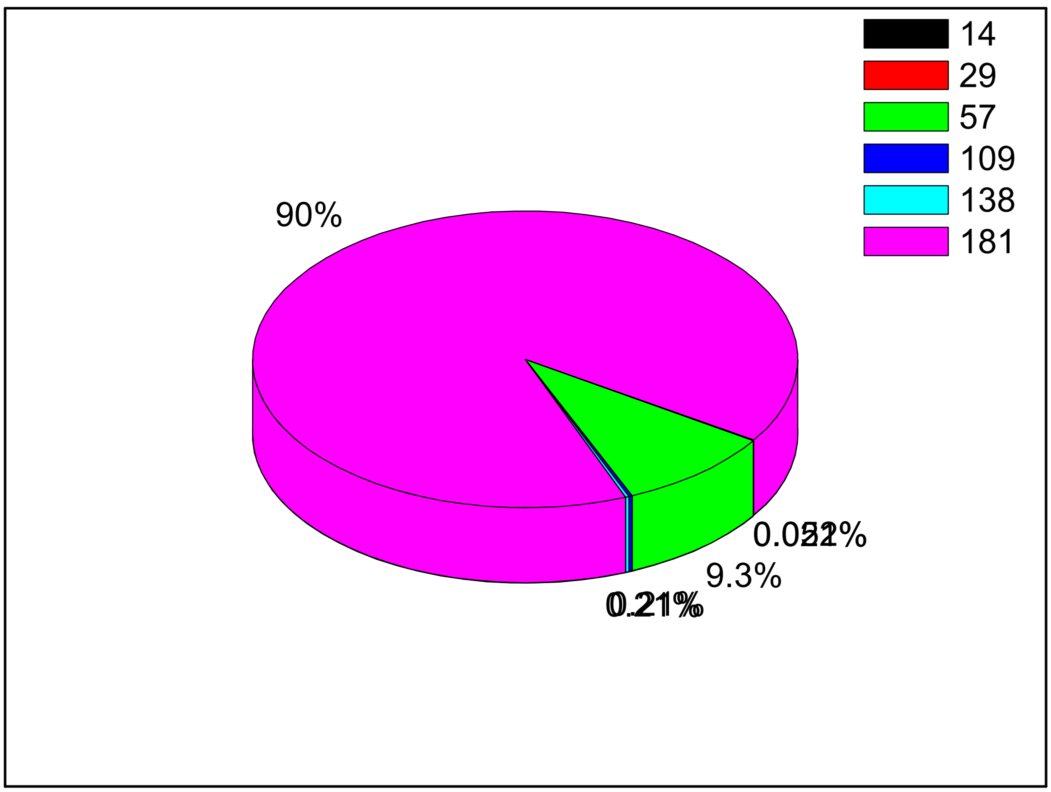

PIE-CHART OF MILL RESIDUE BY REGION OF GAMBIA.

Primary Mill Residues

Data on volume (cubic feet) of primary mill residues in the Gambia was collected from the Timber Products Output Mapmaker version 1.0. Then the following volume conversion factor was used for computations.

1 mcf= 0.0125 MBDT where 1 mcf= 1000 ft 3 and 1 MBDT = 1000 bone dry ton.

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Secondary Mill Residues

Secondary mill residues include wood scraps and sawdust from woodworking shops— furniture factories, wood container and pallet mills, and wholesale lumberyards. The following business categories were included in this analysis:

• Furniture factories: wood kitchen cabinet and countertop, non upholstered wood household furniture, wood office furniture, custom architectural woodwork and millwork, and wood window and door manufacturers

• Millwork: cut stock, re-sawing lumber and planning, and other millwork (including flooring)

• Truss manufacturing

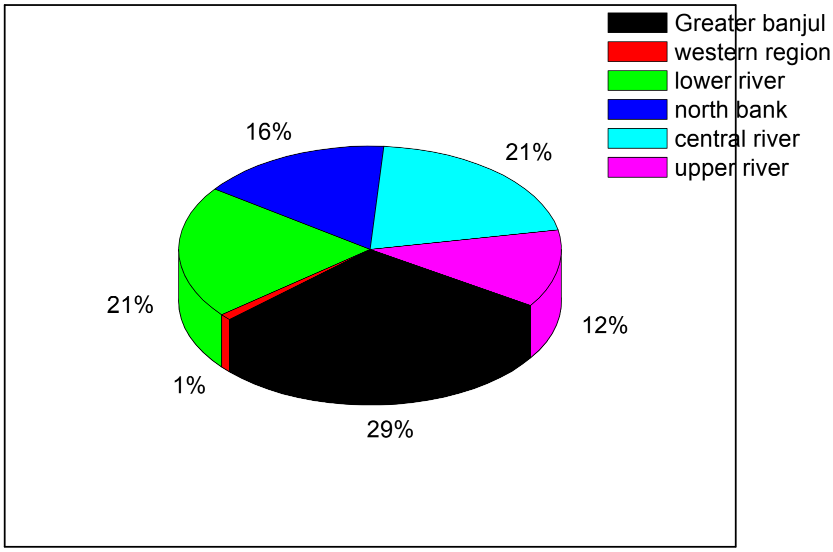
• Wood container and pallet manufacturing

• Lumber, plywood, millwork and wood panel wholesale companies

Data on the number of businesses in Gambia was gathered from the Gambia Census Bureau, 2005 . Depending on the size of a company (number of employees) and assumptions on the wood waste generated by a company derived from Wiltsee's study, the results of this analysis are shown in Table 11. According to this study, pallet and lumber companies generate about 300 tons/year, and a small woodworking company typically generates between 5 and 20 tons/year of wood waste.

Table 11 - Estimated Secondary Mill Residues by Region.

Region.	Secondary Mill Residues (Thousand Dry Tonnes
Greater Banjul	57
Western region	2
Lower river	41
North Bank	32
Central river	41
Upper river	24



PIE-CHART OF SECONDARY MILL RESIDUE BY REGION OF GAMBIA.

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Polynomial Regression for Data1 For Table 11

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	50.2	41.85162
B1	-10.37857	27.38047
B2	1.25	3.82903

R-Square(COD)	SD	N	P
0.05996	23.39577	6	0.91142

Fit and Residual data have been saved into Data1 worksheet.

Independent t-Test on Data1 col(A) and col(B):

Data	Mean	Variance	N
A	--	0	0
B	32.83333	349.36667	6

----

t = --

p = --

At the 0.05 level,

the two means are significantly different.

One-Way ANOVA on columns selected between Col(A) -> Col(B):

Data	Mean	Variance	N
A	--	0	0
B	32.83333	349.36667	6

F = --

p = --

At the 0.05 level, the means are significantly different.

FREQUENCIES

VAR00002

	Observed N	Expected N	Residual
2.00	1	1.2	-.2
24.00	1	1.2	-.2
32.0	1	1.2	-.2

0			
41.00	2	1.2	.8
57.00	1	1.2	-.2
Total	6		

CHI-SQUARE TEST

Test Statistics

	VAR00002
Chi-Square(a	.667

)	
df	4
Asymp. Sig.	.955

a 5 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.2.

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Likelihood Ratio Tests

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	7.541	.585	4	.965

The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Parameter Estimates

VAR00002(a)		B	Std. Error	Wald	df	Sig.
2.00	Intercept	.000	1.414	.000	1	1.000
24.00	Intercept	.000	1.414	.000	1	1.000
32.00	Intercept	.000	1.414	.000	1	1.000
41.00	Intercept	.693	1.225	.320	1	.571

a The reference category is: 57.00.

Secondary Mill Residues

The number of businesses in the Gambia was gathered from the Gambia Census Bureau, 2005Country Business Patterns, and the following methodology was applied:

For pallet and lumber companies:

N * 300 * 0.9072

Where

N - Number of companies in Gambia

300 – According to Wiltsee about 300 tons/year is the wood residue generated by a company

0,9072 - US to metric tons conversion

For woodworking companies:

N * tons/year * 0.9072

Where

N - Number of companies in Gambia

Tons/year - According to Wiltsee's study, a small company typically generates between 5 and 20 tons/year of wood waste. Based on number of employees a conservative assumption of the wood waste generated by a company was applied:

• 1 to 19 employees – 5 tons/year

• 20 – 99 employees – 10 tons/year

• 100 – 499 employees – 15 tons/year

% moisture was assumed for the wood residues generated by the secondary wood products mills

URBAN WOOD RESIDUES.

Three major categories of urban wood residues were considered in this Research work:

• MSW wood—wood chips, pallets, and yard waste
• Utility tree trimming and/or private tree companies
• Construction/demolition wood

Data on the collected urban wood waste are not available; thus numerous assumptions were applied for estimation.

MSW wood and yard waste: MSW per capita by Region was collected from the BioCycle Journal .Then Gambia population data (Gambia Census Bureau, 2005) with assumptions from Wiltsee's study were used to estimate the total MSW generation by Region. According to this research, wood is between 3% and 5% from total MSW, depending on whether wood and yard waste separation and recycling is practiced.

Utility tree trimming and/or private tree companies:

Data on forestry support activities and electric power distribution business establishments in Gambia were gathered from the Gambia Census Bureau, 2005 Country Business Patterns. The assumption that a single tree service crew typically generates about 1,000 tons/year of wood waste was used to calculate the wood waste generated by utility tree trimming and private tree companies.

Construction/Demolition (C/D) wood: The construction and demolition wood was estimated using the following equation adopted from Wiltsee's analysis:

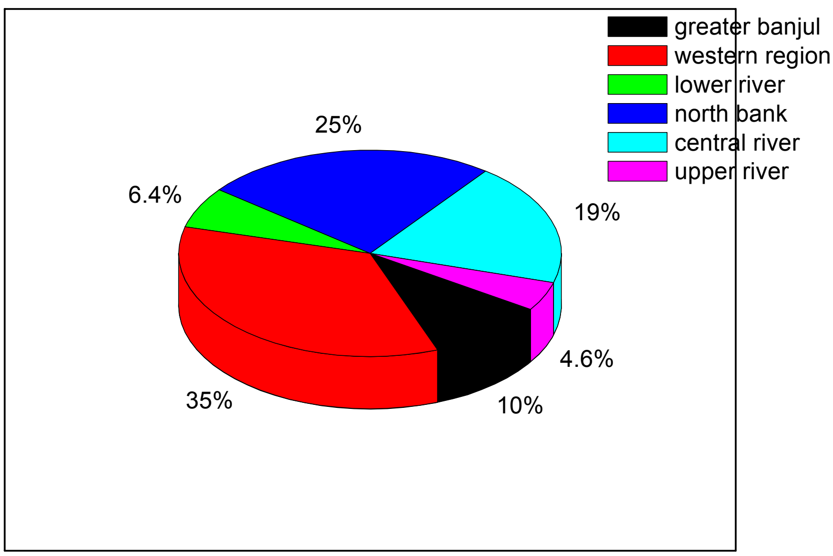
C/D wood, tons/year = 0.09 * Population

Methane Emissions from Landfills

The methane emissions from landfills depend on three key factors: (1) total waste in place; (2) landfill size; and (3) location in an arid or non-arid climate. Data on the landfill locations and the waste in place was obtained from EPA's Landfill Methane Outreach Program (LMOP), 2003 database. For this research work, the landfill size defined by EPA were used. A large landfill is one containing more than 1.1 million tons of waste in place. With regard to moisture as a factor in the methane production, landfills in non-arid climates are believed to produce more methane per unit of waste in place than do landfills in arid climates. Therefore different methane emission estimates have been developed for non-arid regions and for arid regions.

Table 12 - Estimated Methane Emissions from Landfills by Region.

Region.	Methane (Thousand Tonnes
Greater Banjul	11
Western region	38
Lower river	7
North Bank	27
Central river	21
Upper river	5



PIE-CHART METHANE EMMISSION FROM LANDFILLS BY REGION OF GAMBIA.

CHI-SQUARE TEST.

FREQUENCIES.

VAR00002

	Observed N	Expected N	Residual
5.00	1	1.0	.0
7.00	1	1.0	.0
11.00	1	1.0	.0
21.00	1	1.0	.0
27.00	1	1.0	.0
38.00	1	1.0	.0
Total	6		

Test Statistics

	VAR00002
Chi-Square(a)	.000
df	5
Asymp. Sig.	1.000

a 6 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.0.

One-Sample Kolmogorov-Smirnov Test

		VAR00002
N		6
Normal Parameters(a,b)	Mean	18.1667
	Std. Deviation	12.87504
Most Extreme Differences	Absolute	.211
	Positive	.211
	Negative	-.153
Kolmogorov-Smirnov Z		.517
Asymp. Sig. (2-tailed)		.952

a Test distribution is Normal.
b Calculated from data.

One-Sample Kolmogorov-Smirnov Test 2

		VAR00002
N		6
Poisson Parameter(a,b)	Mean	18.1667
Most Extreme Differences	Absolute	.449
	Positive	.449
	Negative	-.302
Kolmogorov-Smirnov Z		1.100
Asymp. Sig. (2-tailed)		.178

a Test distribution is Poisson.
b Calculated from data.

One-Sample Kolmogorov-Smirnov Test 3

		VAR00002
N		6
Exponential parameter.(a,b)	Mean	18.1667
Most Extreme Differences	Absolute	.241
	Positive	.123
	Negative	-.241
Kolmogorov-Smirnov Z		.589
Asymp. Sig. (2-tailed)		.878

a Test Distribution is Exponential.
b Calculated from data.

Small Landfills (WIP< 1.1 MILLION Tons);

Arid: CH_4 (tons/year) = WIP (tons) * 0.27 * 0.0070 Equation 1

Non-arid: H4 (tons/year) = WIP (tons) * 0.35 * 0.0070 Equation 2

Large Landfills (WIP < = 1.1 million tons)

Arid: CH_4 (tons/year) = (WIP (tons) *0.16) + 419023 * 0.0070 Equation 3

Non-arid: CH_4 (tons/year) = (WIP (tons) * 0.26) + 419023 * 0.0070 Equation 4

Where:

WIP – Waste in place

0.27, 0.35, 0.16, and 0.26 - conversion factor for tons of waste to cu.ft./day methane

419023 - Constant recommended in the State Workbook (5-6)

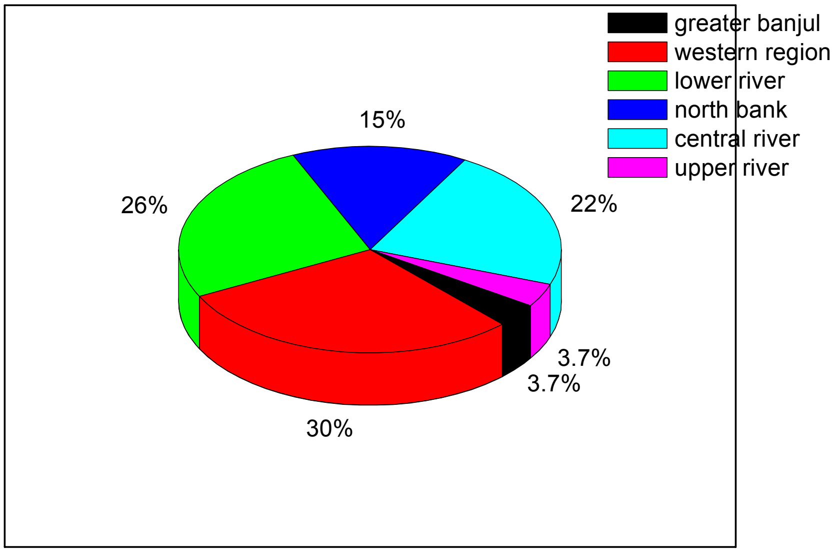
0.0070 - Conversion factor from cu.ft./day to tons/yr or: 365{days/year} x19.2{g/ft3} 453.49{g/ib} x2205{ib}metric ton} == 0.0070 ton CH4 /year. {ft3/day}

Methane Emissions from Domestic Wastewater Treatment

The total methane emissions from wastewater treatment are insignificant compared with other biomass resources; however they may be of importance locally when, by reusing the methane within the facility, a region can reduce greenhouse gas emissions and keep electricity costs low. The treatment process of wastewater from domestic sources (municipal sewage) and industrial sources (pulp and paper; meat and poultry processing; and vegetables, fruits and juices processing) under anaerobic conditions (i.e., without oxygen) results in methane emissions. This study estimates the methane emissions from domestic sources using the methodology from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003 The results are displayed in Table 13.

Table -13 Estimated Methane Emissions from Domestic Wastewater Treatment by Region.

Region	Methane (Thousand Tonnes
Greater Banjul	1
Western region	8
Lower river	7
North Bank	4
Central river	6
Upper river	1



PIE-CHART OF METHANE EMMISSION FROM DOMESTIC WASTE WATER BY REGION OF GAMBIA.

CHI-SQUARE TEST.

FREQUENCIES.

VAR00002

	Observed N	Expected N	Residual
1.00	2	1.2	.8
4.00	1	1.2	-.2
6.00	1	1.2	-.2
7.00	1	1.2	-.2
8.00	1	1.2	-.2
Total	6		

Test Statistics

	VAR00002
Chi-Square(a)	.667
df	4
Asymp. Sig.	.955

a 5 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.2.

One-Sample Kolmogorov-Smirnov Test

		VAR00002
N		6
Normal Parameters(a,b)	Mean	4.5000
	Std. Deviation	3.01662
Most Extreme Differences	Absolute	.210
	Positive	.210
	Negative	-.190
Kolmogorov-Smirnov Z		.515
Asymp. Sig. (2-tailed)		.953

a Test distribution is Normal.
b Calculated from data.

One-Sample Kolmogorov-Smirnov Test 2

		VAR00002
N		6
Poisson Parameter(a,b)	Mean	4.5000
Most Extreme Differences	Absolute	.272
	Positive	.272
	Negative	-.203
Kolmogorov-Smirnov Z		.667
Asymp. Sig. (2-tailed)		.765

a Test distribution is Poisson.
b Calculated from data.

One-Sample Kolmogorov-Smirnov Test 3

		VAR00002
N		6
Exponential parameter.(a,b)	Mean	4.5000
Most Extreme Differences	Absolute	.256
	Positive	.169
	Negative	-.256
Kolmogorov-Smirnov Z		.626
Asymp. Sig. (2-tailed)		.828

a Test Distribution is Exponential.
b Calculated from data.

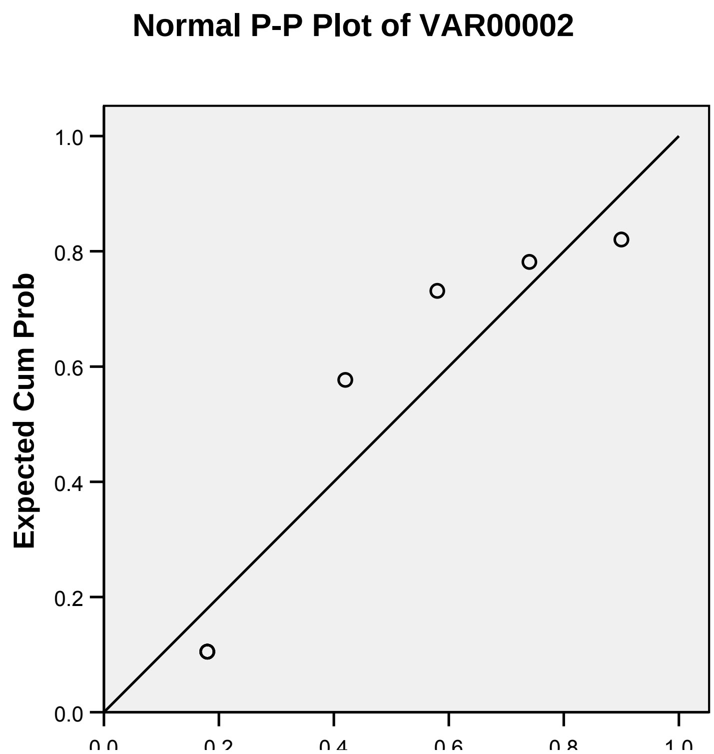
T- TEST.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	6	4.5000	3.01662	1.23153

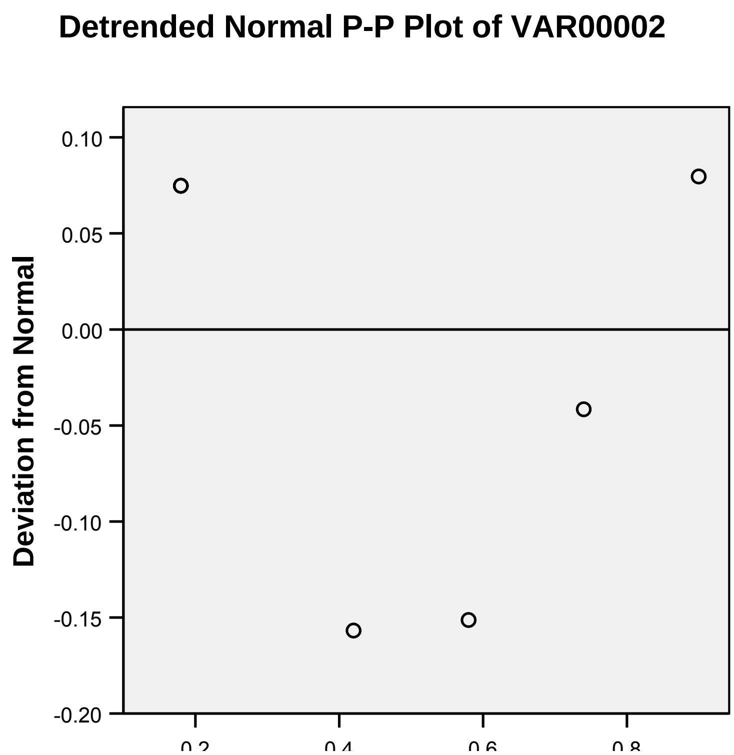
One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
VAR00002	3.654	5	.015	4.50000	1.3343	7.6657



Observed Cum prob.

Transform-natural log



Observed Cum prob.

Transform –natural log

Methane Emissions from Domestic Wastewater Treatment

Methodology adopted from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001, Wastewater Treatment.

Methane (CH_4) Generation = (POP) * (BOD) * (PAD) * (CH4P)

Where

POP = country population (2000 Census data)

BOD = production of BOD per capita per year (0.065 kg of wastewater BOD is produced per day per capita)

PAD = percentage of BOD anaerobically digested per year (16.25%)

CH4P = methane generation potential per kg of BOD (emission factor of 0.6 kg CH_4/kg of BOD)

An aerial transects was set up over a mixed hardwood/closed forest managed by Gambia National Environmental Agency {NEA} .NEA provided forestry support personnel to assist in measuring thirty-one plot sites along two aerial transects over the forest . The center of each plot was established within known tree stands that represented samples of mature and regenerating hardwoods, thinned hardwoods, and mangroves plantations. Three criteria were used to select plot locations: 1) at least 100 m from roads, 2) along the target transects, and 3) in an area which was representative of the vegetation around it within a 100 m radius. Using a GPS receiver, the field crews navigated to each plot and marked the center with a four-foot metal stake. Estimates of understory vegetation, standing litter and soil biomass were collected from clip plots, but the vast majority of the standing biomass for each plot was estimated directly from the dbh values of measured trees, using species-specific allometric equations .Equations of this kind are available for temperate tree species of the Gambia (Tritton and Hornbeck, 1982) and tropical tree species (Crow, 1978; Brown et al., 1984, 1989). Equations for temperate trees exist for individual species and for groups (e.g., all pines, all hardwoods) and have been generated over many different studies by measuring the trees, then actually cutting them down, drying and weighing them.

Regression equations were developed to describe above ground biomass as a function of dbh alone or dbh and height. The differences in the equations reflect variations in wood density and tree allometry (relative mass in each component). The conifer/broadleaf distinction is usually the most important for both of these factors when grouping species, therefore the equations for tropical species are usually for all species in a single group. (In Gambia only hardwoods and palm-trees are distinguished}

Table 14 - Biomass equations used for the Gambia test site

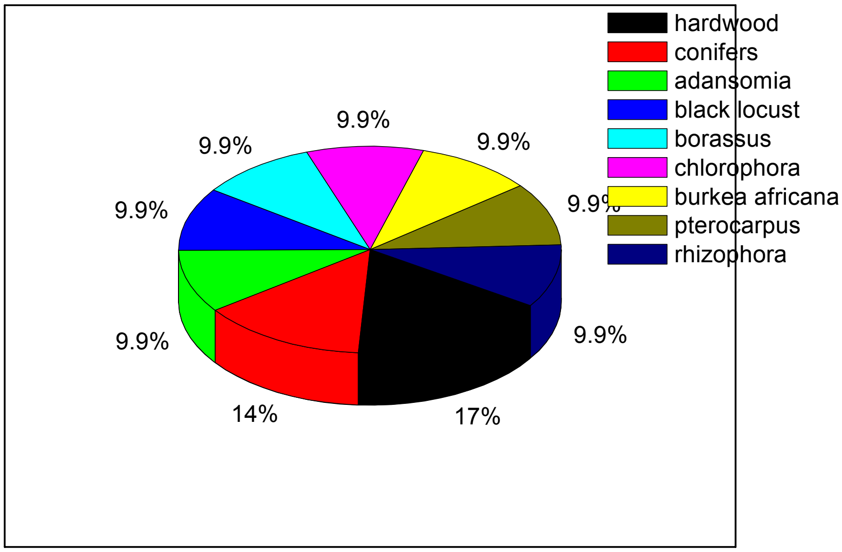
Species.	Equation	Dbh range and mass
Hardwoods	y = 0.5 + ((25,000*dbh^2.5)/(dbh^2.5+246,87	1-85 cm Kilogram
Conifers	y = 0.5 + ((15,000*dbh^2.7)/(dbh^2.7+364,946)	3-71 cm Kilogram
Adansonia digitata	y = 3.2031-(0.2337*dbh)+(0.006061*dbh^2	5-50 cm Kilogram
Black locust	y = (Exp(0.45689 + 2.6087 * (Log(dbh))))*0.45	5-50 cm Kilogram
Borassus aeithiopum	y =0.5 + ((25,000*dbh^2.5)/(dbh^2.5+246,872)	5-50 cm Kilogram
Chlorophora regia	y =0.5 + ((25,000*dbh^2.5)/(dbh^2.5+246,872)	5-50 cm Kilogram
Burkea Africana	y =Exp(-2.3684 + 2.5303 * (Log(dbh))	5-50 cm Kilogram
Pterocarpus	y = (2.4601*(dbh^2.4572))*.45	5-50 cm Kilogram
Rhizophora racemosa	y = (1.8082*(dbh^2.6174))*.45	5-50 cm Kilogram

Where: y = biomass in kilograms, Exp = raised to the power of, dbh =diameter at breast height.

Dbh and species were the principal measures used by the researcher to calculate tree biomass in their plot sites.

Therefore, the goal in an aerial survey was to find if measurements of crown diameter made from the air could be sufficiently correlated to stem diameter to accurately calculate the dbh of trees visible in the canopy. The Gambia Department of Forest Service recently completed a forest health survey of the Gambia in which both dbh and crown diameter measurements were taken from over 750 different tree specimens. Two measurements were made from each crown, its largest diameter and a second value directly perpendicular to the first measurement, the data were correlated and regression equations between average crown diameter and dbh for each species found at the Gambia test site developed.

Two approaches were taken to aerial coverage of the sites, essentially 3D and 2D. In the 3D approach, a small format photogrammetric camera was used to develop a bundle adjusted 3D model of each transect using a CVRL developed auto digital elevation modeling program called Terrest . This photographic coverage was flown at an altitude of 4,000 ft. above ground with a calibrated Hasselblad MKW camera. Images were exposed onto 70 mm film and digitally scanned at a resolution of 40 centimeters per pixel, with 80% overlap between frames. A Trimble real-time differential GPS (DGPS) was used for in-flight navigation and georeferencing data. An on-board computer recorded the GPS data and fired the camera at predetermined geographic locations. It also recorded the exact time of each exposure and the corresponding output from a Watson digital gyroscope, which was mounted on the same plane as the camera so that its precise orientation in space could be determined. The excessive overlap was necessary to maintain radiometric consistency in the 3D model generated from the coverage and was made practical by the use of a small format camera and automated digital image handling techniques. Working within this 3D space in a fly-through image-processing program, it was easy to identify and measure individual crowns, but very computer intensive and time consuming.



PIE-CHART OF BIOMASS SPECIES & DBH RANGE FOR GAMBIA TEST SITE.

Polynomial Regression for Data1_A:

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	95.5	6.82336
B1	-15.5803	3.13302
B2	1.2197	0.30556

R-Square(COD)	SD	N	P
0.86905	5.36251	9	0.00225

Fit and Residual data have been saved into Data1 worksheet

Independent t-Test on Data1 col(A) and col(B):

Data	Mean	Variance	N
A	-- 0	0	
B	56.22222	164.69444	9

t = --

p = --

At the 0.05 level,

the two means are significantly different.

CHI-SQUARE TEST.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	9	56.2222	12.83333	4.27778

One-Sample Test

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
VAR00002	13.143	8	.000	56.22222	46.3576	66.0868

Test Statistics

	VAR00002
Chi-Square(a)	8.000
df	2
Asymp. Sig.	.018

a 3 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 3.0.

One-Sample Kolmogorov-Smirnov Test

		VAR00002
N		9
Normal Parameters(a,b)	Mean	56.2222
	Std. Deviation	12.83333
Most Extreme Differences	Absolute	.464
	Positive	.464
	Negative	-.314
Kolmogorov-Smirnov Z		1.392
Asymp. Sig. (2-tailed)		.042

a Test distribution is Normal.
b Calculated from data

One-Sample Kolmogorov-Smirnov Test 2

		VAR00002
N		9
Poisson Parameter(a,b)	Mean	56.2222
Most Extreme Differences	Absolute	.552
	Positive	.552
	Negative	-.190
Kolmogorov-Smirnov Z		1.657
Asymp. Sig. (2-tailed)		.008

a Test distribution is Poisson.
b Calculated from data.

One-Sample Kolmogorov-Smirnov Test 3

		VAR00002
N		9
Exponential parameter.(a,b)	Mean	56.2222
Most Extreme Differences	Absolute	.589
	Positive	.220
	Negative	-.589
Kolmogorov-Smirnov Z		1.767
Asymp. Sig. (2-tailed)		.004

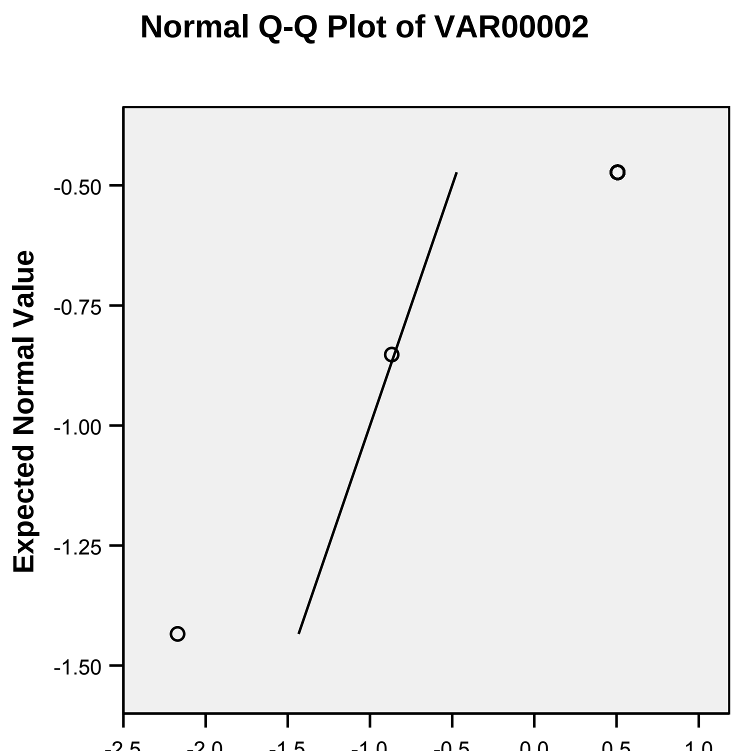
a Test Distribution is Exponential.

b Calculated from data.

Model Description

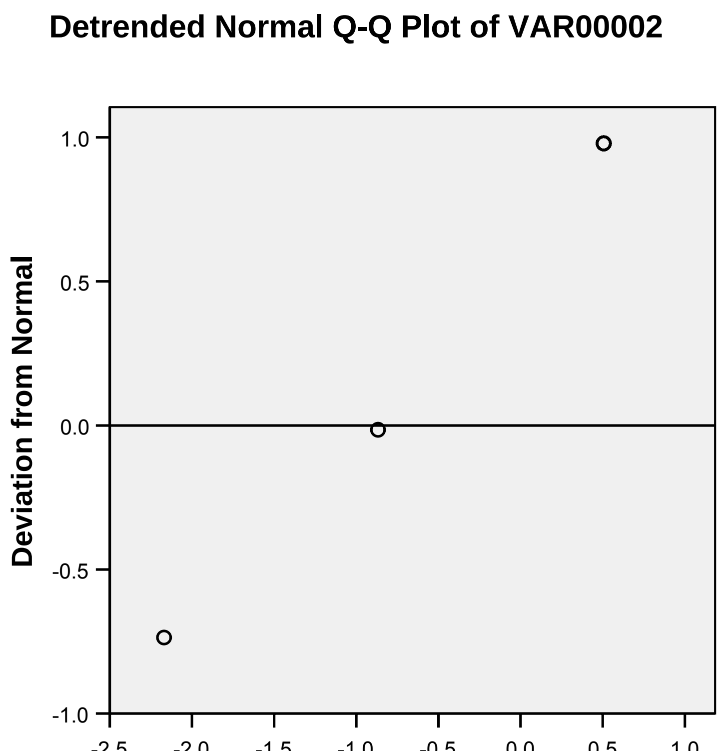
Model Name	MOD_2
Series or Sequence 1	VAR00002
Transformation	Natural logarithm
Non-Seasonal Differencing	1
Seasonal Differencing	0
Length of Seasonal Period	No periodicity
Standardization	Applied
Distribution Type	Normal
Location	Estimated
Scale	Estimated
Fractional Rank Estimation Method	Blom's
Rank Assigned to Ties	Lowest rank of tied values

Applying the model specifications from MOD_2



Standardized observed value.

Transform- natural log ,difference (1)



Standardized observed value.

Transform –natural log, difference (1)

Table -15 Regression equations generated from Gambia Department of forest health survey data.

SPECIES	REGRESSION	NUMBER OF POINTS.
Hardwood	Y=1.25310+.03280x	4452
Conifers	Y=1.00709+.03693x	369
Adansonia digitata	Y=2.08342+.04305x	626
Black locust	Y=1.31445+.04100x	448
Borassus aeithiopum	Y=2.11935+.02495x	329
Chlorophora regia	Y=6.89910+.01185x	99
Bulkea Africana	Y=0.12001+.05036x	379
Pterocarpus	Y=1.04406+.03877x	540
Rhizophora racemosa	Y=1.70664+.04169x	219

TOTAL NUMBER OF POINT =7461.

Model Description

Model Name		MOD_1
Dependent Variable	1	VAR00002
Equation	1	Linear
	2	Logarithmic
	3	Growth(a)
	4	Exponential(a)
Independent Variable		Case sequence
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified

a The model requires all non-missing values to be positive.

Case Processing Summary

	N
Total Cases	9
Excluded Cases(a)	0
Forecasted Cases	0
Newly Created Cases	0

a Cases with a missing value in any variable are excluded from the analysis.

ANOVA

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	4966277.400	1	4966277.400	3.477	.105
Residual	9998842.600	7	1428406.086		
Total	14965120.000	8			

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Case Sequence	-287.700	154.294	-.576	-1.865	.105
(Constant)	2267.500	868.263		2.612	.035

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
ln(Case Sequence)	-1449.651	465.128	-.762	-3.117	.017
(Constant)	2891.020	732.950		3.944	.006

Growth

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.599	.359	.267	.876

ANOVA

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	3.001	1	3.001	3.912	.088
Residual	5.370	7	.767		
Total	8.372	8			

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Case Sequence	-.224	.113	-.599	-1.978	.088
(Constant)	7.214	.636		11.338	.000

The dependent variable is ln(VAR00002).

Exponential

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.599	.359	.267	.876

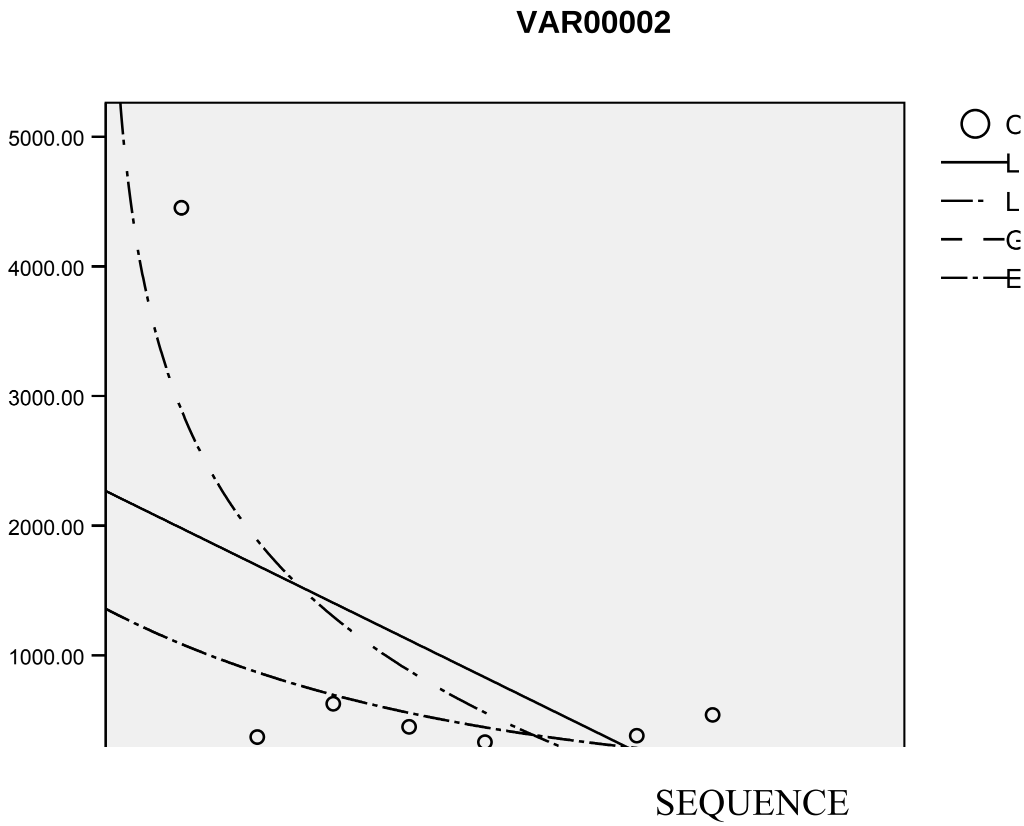
ANOVA

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	3.001	1	3.001	3.912	.088
Residual	5.370	7	.767		
Total	8.372	8			

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Case Sequence	-.224	.113	-.599	-1.978	.088
(Constant)	1358.881	864.683		1.572	.160

The dependent variable is ln(VAR00002).



Likelihood Ratio Tests

The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Parameter Estimates

VAR00002(a)		B	Std. Error	Wald	df	Sig.
99.00	Intercept	.000	1.414	.000	1	1.000
219.00	Intercept	.000	1.414	.000	1	1.000
329.00	Intercept	.000	1.414	.000	1	1.000
369.00	Intercept	.000	1.414	.000	1	1.000
379.00	Intercept	.000	1.414	.000	1	1.000
448.00	Intercept	.000	1.414	.000	1	1.000
540.00	Intercept	.000	1.414	.000	1	1.000
626.00	Intercept	.000	1.414	.000	1	1.000

a The reference category is: 4452.00.

The 2D approach utilized video coverage of individual crowns at a much larger scale in conjunction with laser range finder data. Two Canon ES 500 Hi8 camcorders were then flown over each site at an altitude of 1,000 ft. above ground, providing video coverage at two different scales. One camera was set at wide-angle coverage providing a swath approximately 320 meters wide, with 50 centimeter per pixel resolution. The other camera was set at 12X zoom, recording a 26 meter wide swath at 4 cm per pixel resolution, a sufficient scale to identify individual tree species. A Horita time code generator wrote the Trimble GPS time code and frame number to each video frame as a record of their geographic locations. It also logged the output from the Watson digital gyroscope and a pulse-modulated laser mounted in a vertical mode to provide a continuous profile of the canopy by sending a series of 248 pulses per second along the flight path. The laser beam was approximately one meter wide at the canopy surface and the instrument was set to record the last return on each pulse for maximum penetration to the ground. It was bore-sighted to the large scale zoomed video to identify sensor penetrations that clearly reached the forest floor and provided a measure of canopy height along each flight line. For the Gambia coverage, the Hi8 cameras with a DV digital system, replaces that with higher resolution progressive scan cameras that will download directly to an on-board raid array.

At the inception of this research work, I did not know how well the video / laser combination would work, as compared to a full 3D reconstruction from the calibrated camera. However, as the imagery was compiled and interpreted, it became obvious that the 2D approach was the most cost effective and accurate. The principal reason for this was that the identification of individual tree species and measurement of their crowns remained a manual photo-interpretation task. At present, the 3D reconstructions are computer intensive and time consuming to produce even with automatic, pixel specific, digital elevation models. Tree crown and heights can be easily identified and measured in a 3D fly-through image processing environment, but species identification is more problematic at the 40 centimeter per pixel resolution. Also, the manipulation of these models, even at that resolution, is frustratingly slow and difficult with the desktop computers used.

However, other work within the project had developed an automated geo-referencing and mosacking program that utilized the Watson gyroscope and laser data to rectify each video frame into an accurate strip of the ground (Zhu et al., in press). This made it practical to construct strip mosaics of the zoom video and delineate hectare size plots of 20 by 500 meters. At a pixel resolution of 4 centimeters, species could easily be identified and each crown fitted with a circle that averaged its diameter. Combined with the laser profile, this produced a simple model of the forest from which dbh values and heights, could be calculated.

For the purposes of this research work then, the analysis was concentrated on manually measuring crowns within one-hectare linear strips from the zoomed video coverage, calculating the dbhs and percent canopy coverage for all visible trees within those strips. This was easily accomplished within a 2D GIS environment using the object edit program. Circles were fitted over each tree as CAD drawings, which preserved the center coordinates and diameter of each circle in the file database. After a first pass to draw the crown diameters, that file was edited for species type in conjunction with the laser data to attach a height value to each tree. Trees not directly measured by the laser were labeled with an average height for the stand, an average emergent height, or average understory height based on their size and shadow cast. The database for these drawings was then exported to Excel, where a dbh value for each tree was calculated from their crown diameters and the regression equations developed . Because the circles in the CAD drawings tended to overlap, they were then converted to vector files with contiguous polygons that could be summarized to determine the percent coverage of canopy in each hectare plot.

Unfortunately, several of the plot sites in the Gambia were made within very localized stand conditions, which meant that the video strips had to hit them directly or pass within that stand in order to make a valid comparison. Inasmuch as the original GPS coordinates for the plots were not differentially corrected, this was as much a matter of luck as accurate aircraft aiming. The conifer stands were the most difficult, with only a half-hectare captured of one. I did not expect this to be a problem in Gambia where the plots coordinates are differentially corrected and I was using real time DGPS with an ministar satellite.

I was able to analyze and compare 10 video strips, most of which spanned the distance between two sites in a homogeneous community, although the size of the strip had to be reduced in several cases to fit within the stand type. When a strip crossed a road or naturally no forest clearing, the plot would collapsed then reopened on the other side so that only normal or thinned breaks in canopy coverage were included. The average dbh for each strip was then compared to the average dbhs for their corresponding sites.

The video strips are divided by tree type, showing the plot size, number of trees counted and the percentage of the canopy coverage. You would note that canopy cover ranges from as low as 65% in a mature thinned hardwood stand to as high as 92% in an eight year old stand of regenerating trees. These is as I would expect and I anticipate that one of the advantages of using this kind of linear swath through the landscape is that the sample will be a more accurate reflection of the natural and man-made breaks in the canopy than may be captured by a series of 28 meter plots. The number of trees per hectare predicted by these strips is calculated and compared to the number of trees per hectare calculated from the corresponding plot sites. Two sets of columns are presented for both the video strips and the corresponding plot sites. The first column for the video estimates the total number of trees per hectare based on the measured percentage of canopy coverage. The second column estimated the number based on the assumption that 100% canopy coverage, as would often be the case if the estimate were extrapolated from a single plot site. The first column of plot calculations shows the range of tree estimates for the two plot sites covered by the hectare video strip. These estimates are achieved by multiplying the outer plot count by 16.25 and the inner plot by 201.2, essentially extrapolating the site counts to a hectare sized area. The second column averages those two values after removing the understory of trees less than 7 cm in diameter, which I did not appeared to be measuring in the aerial count, but which contributed only a small fraction to the standing biomass. What is striking about these two column sets is the difference between the calculated number of tree between sites that are supposedly within a homogenous stand of vegetation. Given that range of variability it is difficult to determine which estimate of tree numbers per hectare is the more accurate, although it appears obvious that the video is undercounting the smaller trees in the 20 year re-growth and the plot site calculations tend to over- estimate the percentage of canopy coverage.

However, I do have very good correlations between the averages of measured and calculated dbh for each stand, measurements that are not dependent on the estimation of a larger population from small sites. The last column divides the average measured dbh of the combined ground plot sites by the average calculated dbh of their video strips. A perfect ratio match would be a value of 1, and the admittedly small population of mature hardwoods represented here has a Pearson sample correlation coefficient of r =.8757, indicating a very strong positive match between the measured and calculated values given a larger sample base, I could probably develop a correction factor to better characterize that type of stand. It is difficult to directly compare the plot site values to video strip values when I did not have precise locations for the plots, but a review of size distribution within the mature hardwoods for both video strips and sites, indicates that I appeared to be missing the smallest trees and overestimating the sizes of the medium size trees, but that this is somewhat canceled out by a consistent underestimate of the largest trees. These are also adjustments that could be corrected for in a larger ground sample population.. I had precise differentially corrected locations for most of the 35 plot sites and are confident of hitting at least 40 sites with sufficient accuracy to image the plot in the zoom. Crown diameters were not measured in the original plots established by the researcher, but I expect to develop regression equations directly from my analysis of the site images by identifying the major trees, or correlating the total structure of the 28-meter diameter of the trees to the site biomass values.

GIS is considered an effective tool to addressing issues related to biomass availability and cost, and issues related to bioenergy facility locations (Graham et al., 2000). Graham et al. (2000) applied GIS using a state-level modeling system for estimating regional geographic variations on energy crop feedstock costs and supplies (farm-gate and delivered), and environmental effects of switching from conventional crops to energy crops. Haddad and Anderson (2008) applied GIS to identify potential supply locations of corn stover for bioenergy production.

Voivontas et al. (2001) estimated the biomass potential for power production from agriculture scraps based on GIS.

The methodology consists of two phases of analysis: (1) identify potential pulpwood-to-biofuel facility locations based on a GIS approach (phase I), and (2) selection of the optimal biofuel facility location based on a weighted-average transportation cost model (phase II). Figure 5 outlines the steps in each phase and shows the relationship between the two phases.

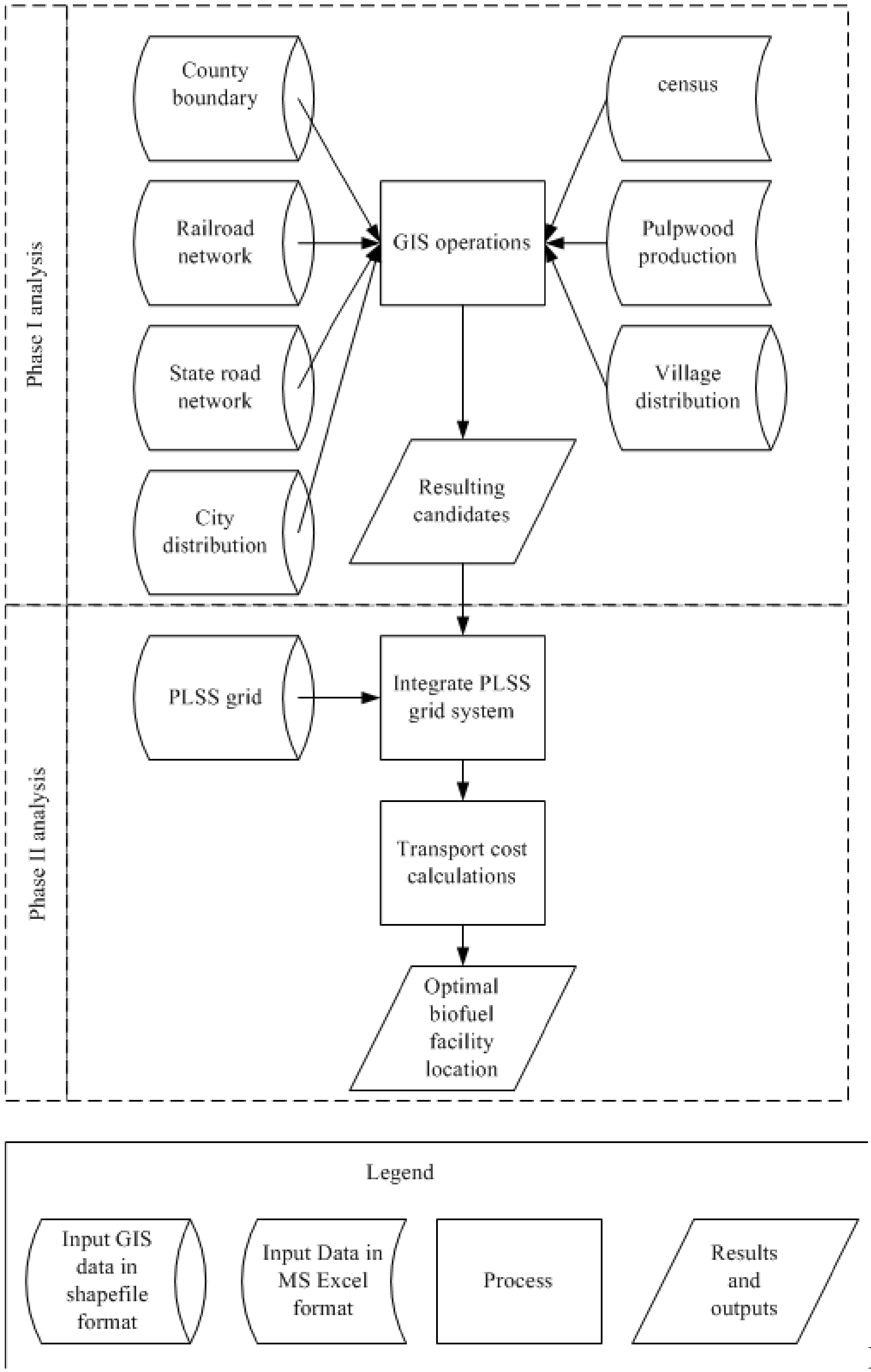


Figure 4.5 overview of the methodology used.

In phase I (Figure 5), GIS is used to identify potential pulpwood-to-biofuel facility locations. The required data for the GIS analysis included six categories: country boundary, Gambia road transportation network, city distribution, village distribution, population census, and pulpwood production. Prior to analysis, it is necessary to make several assumptions regarding the application of GIS:

• The unit of measure of pulpwood is commonly in million cubic feet. A conversion factor of 30 lb per cubic feet is used.

• Only one percent of pulpwood production is available for biofuel production. The one percent assumption of pulpwood used for biofuel production is based on the consideration of sustainable harvesting of forest resources and competition for the raw material from other biofuel and bioproducts industries and the pulp and paper industries.

• Because the pulpwood production information is country-based, a uniform distribution was used to describe pulpwood production within each region of Gambia..

• The biomass conversion plant has a medium capacity production of 20 million gallons of biofuel per year (Tembo et al., 2003)

Based on a conversion yield of 60 gallons/dry ton of biomass (Aden et al., 2002), the biofuel facility will have a demand for approximately 70,000 dry tons of feedstock per year.

• The trucking distance (haul radius) is 50 miles or less, with the biofuel facility location at the center of the biomass harvesting area.

• The biofuel facility is accessible to Gambia road (i.e., the facility is within one mile of a network). This guarantees the input (pulpwood feedstock) and output (biofuel products) can be easily transported.

• The biofuel facility will be located in a region or village with a population greater than 1,000 to ensure that enough workers are available for the plant.

After the assumptions were made, the GIS operations involved in identification of potential locations for pulpwood-to-biofuel facilities are detailed. GIS operations are the central part of the methodology of the first phase of the analysis. The operations consist of the 7 steps described below.

1) Create a geodatabase to include all input features used for analysis;

2) Join pulpwood information to Gambia;

3) Calculate tons per square mile within each region of the Gambia

4) Join population census information to regions and villages;

5) Build a one-mile buffer around Gambia roads.

6) Select regions and villages within the regional roads buffer;

7) Select regions and villages with a census population greater than 1,000.

After completing the phase I analysis, additional information is available to complete phase II of analysis.

The objective of phase II (Figure 5) of analysis is to identify the best location for biofuel production from forest biomass. A preliminary selection of potential sites was performed in phase I based on the GIS approach by examining a series of decision factors. Potential sites identified from phase I, including regions and villages, were transferred into point geometry that represent demand points. The PLSS1 grid system (1 mile x 1 mile) was used as the minimum information unit over the study area. A weighted-average transportation cost model was developed. The optimal site for biofuel production from forest biomass was identified to be the one with the minimum weighted-average transportation cost.

The transportation cost model used for the analysis was developed by Hicks et al. (2009). Three companies from Gambia were investigated for their tariff rate structures and used to develop the model for the Upper river region of Gambia. All of the tariff rates were converted to GMD per ton and plotted against transportation distance. Linear regression was used to fit a line to the tariff rate data. Equation provides the transportation cost CT, in GMD per mile per ton

$.CT= 3.89+ 0.067 * d +0.0114 * \{Cf = 2.67\} *d$

where CT is the one-way transportation cost (GMD/ton) from a supply point to a demand point, d is the one-way transportation distance (miles) from a supply point to a demand point, and Cf is the fuel price (GMD/gallon). The coefficient of determination for the fitted line was $R2 = 0.9703$. The equation consists of three components: base cost, mileage cost, and fuel cost differential. The base cost rate of GMD3.89/ton covers the cost of loading and unloading .The fuel cost differential term arises because the average fuel cost of GMD2.67/gal, as was the case in Oct 2009, will not be the case in general. If the fuel cost rate is indeed GMD2.67/gal, the one-way transportation cost, CT, simplifies to:

$Ct= 3.89 + 0.067 * d.$

The transportation cost model was used in the section below to build the weighted-average transportation cost model.

Candidate facility locations are referred to as demand points (j = 1, 2, 3, …, m). Take one demand point for example, the 50-mile biomass harvesting area for the demand point is divided into n cells (the area of each cell is one square mile). A pixel is placed at the centroid of each cell, and this pixel serves as the supply point for the cell. Associated with each supply point i (i = 1, 2, …, N) is the quantity (Qi) of pulpwood available. The quantity of pulpwood Qi is calculated as:

$$(1)\quad Qi = \frac{Qc * Ai}{Ac} \qquad \{1\}$$

where Qc is the total quantity of pulpwood available in a county, Ai is the area of cell or pixel i, and Ac is the area of a country.

The Euclidean distance is calculated between any pair of supply and demand points and used as the distance in the transportation cost model. A per unit transportation cost Cij is calculated using the transportation cost equations. The transportation costs are sorted from the lowest to the highest.

The available quantity of biomass Qi at each supply point is summed (Sj) beginning with the lowest transportation cost until the sum meets or exceeds 70,000 tons. When this condition is met, Dj is set equal to Sj (Equation (2)).

$$Dj = Sj = \Sigma Qj \qquad \text{--------}\{2\}$$

where Qi is the available quantity of biomass at each supply point, Sj is the total quantity of biomass available from the n supply points, and Dj is of the amount of biomass feedstock required at each demand point. The weighted-average transportation cost Cavg(j) is calculated in Equation i.e., the transportation cost is weighted by the available biomass at each supply point.

$$C\ avg\ [j] = \frac{\sum [\ - 1\{Cij * Q1\}}{DJ} \qquad \ldots\ldots\ldots\ldots\ldots..3$$

where Cij is per unit transportation cost (GMD/ton) and Cavg(j) is weighted-average transportation cost (GMD/ton).

The weighted-average transportation distance, Lavg(j), is calculated in Equation (4):

$$Lavg\ \{j\} = \frac{\sum - 1\ \{Lij * Qi\}}{Dj} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..4$$

where Lij is the Euclidean distance between any supply point i and any candidate facility location..

Table 16 - Farm boundary fruit tree planting.

Year	Number of trees	Cumulative number of trees	Areas {ha}	Annual growth increment	Biomass	Equivalent t CO2 absorbed
1	20.000	20,000	800	14.5	1,600	2,933
2	20.000	40,000	1,600	29.0	46,400	85,065
3	20.000	60,000	2,400	43.5	104,400	191,397
4	20.000	80,000	3,200	58.0	185,600	340,260
5	20.000	100,000	4,000	72.5	290,000	531,657
6	20,000	120,000	4,800	87.0	417,600	765,586
7	20,000	140,000	5,200	101.5	527,800	967,616

Table -17 Private (forest) farm lands on degraded site

Year	Number of trees	Cumulative number of trees	Areas {ha}	Annual growth increment	Biomass	Equivalent t CO2 absorbed.
1	7,500	7500	50	12.5	625	1,146
2	7,500	15,000	100	25.0	2,500	4,583
3	7,500	22,500	150	37.5	5,625	10,312
4	7,500	30,000	200	50.0	10,000	18,333
5	7,500	37,500	250	62.5	15,625	28,645
6	7,500	45,000	300	75.0	22,500	41,249
7	7,500	52,500	350	87.5	30,625	56,145

Sustainability criteria for the use and management of forests include ecological, social, and economic components. This forestland suitability analysis focuses explicitly on environmental factors. Neither economic nor social factors, such as landowner management objectives and preferences regarding forest aesthetics, have been addressed in our woodshed analysis, but such factors, of course, play large roles in determining the available wood supply. We use the word ‘suitable’ to denote the forestland area that has characteristics indicating that wood could be harvested sustainably and does not carry legal protections prohibiting timber extraction. That is, if timber harvest were conducted, it could be done so on those lands in ways to avoid degrading soils, tree productivity, water quality, and high-elevation lands.

Ecological criteria for sustainability refer to forest health, productive capacity, soil and water, biodiversity, and carbon and nutrient budgets (Raison 2002). These criteria cover the spectrum of a forest’s organisms, land-, air-, and water-scapes, and ecological processes. Therefore, sustainable resource extraction is based upon not only how a forest is managed and utilized, but where in a forest different types and intensities of utilization occur. It is widely accepted that some forestlands are not capable of sustainable timber extraction, and among those that are capable, not all extraction systems are equally suited to all lands (Seymour and Hunter 1999, Lindenmayer and Franklin 2002). It is also recognized that for ecological sustainability there is a need to preserve representatives of all ecological land types—even those that may be highly suited to sustainable resource extraction—with conservation protections that prohibit resource extraction (Pressey et al. 1993, Noss and Cooperider 1994, Poiana et al. 2000).

Numerous physical site characteristics may be used to define and delineate lands suitable for sustainable intensive forestry. Our analysis has used characteristics for which spatial data were readily available. Given the wealth of geographic information available ,I was able to account for the most important physical factors. I was not able to include information about exemplary representations of different ecosystems (i.e., natural communities) because of the lack of available field-verified information regarding presence and location of such lands in the study areas.

Soils characteristics, topography, and elevation are of paramount importance in determining which lands are suitable for sustainable biomass harvest, because the productive capacity of a forest and the resilience or fragility of a site are intimately linked to these physical characteristics (Richter 2000). The greater the removal of biomass from a site, the more likelihood there is for greatly altering the nutrient status and physical and chemical characteristics of the soil (Hendrickson 1988, Hornbeck 1992, Martin et al. 2000). Therefore, when harvests include removals of substantial amounts of low-quality wood for biofuel, it is especially important to be aware of the site's ability to retain nutrients and the soil's ability to maintain its physical structure and nutrient-holding capacity. Forest land value group (Gambia-Soil Conservation Service 1997), slope, and elevation data were used in the land suitability analysis to account for these important physical characteristics.

Water quality and aquatic ecosystems can be detrimentally affected by timber harvest activities in a forest; more intensive harvesting leads to increased leaching of nutrients into streams and increased stream temperatures (Hornbeck et al. 1986, Hornbeck et al. 1990, Richter 2000, Schaberg 2002). Streamside management zones that include riparian buffers and strict adherence to country-sanctioned, Acceptable Management Practices (AMPs) for stream crossings are very effective at reducing impacts on aquatic ecosystems (Hornbeck et al. 1986, Department For Sustainable Forests 2000). On lands with 0-60% slope, Gambia AMPs call for 50-150' buffers around streams, lakes, and ponds, with the wider buffers needed on steeper lands (Gambia Department of Forests, Parks and Recreation 1987). My analysis incorporated a standard 75' buffer around all surface waters. Wetlands were also buffered to a width of 75', as wetlands are recognized both as being important breeding and feeding habitat for numerous animals and serving important functions for maintaining water quality and supply (Water Resources Board 1990).

The analysis to identify the forested lands suitable for biomass harvesting was conducted using ArcGIS 9.3 (ESRI 2008). Land suitability was based on criteria discussed above in the rationale. Physical characteristics considered were slope, elevation, soils, and surface waters and wetlands with adjacent 75' buffers.

Legal protection status of conserved lands was also considered, which allowed us to determine which lands would be available for legal harvest.

All data layers were constrained or “clipped” to the study area. To conduct analyses, all data layers that were not published in raster (pixel-based) format were rasterized at a 30m pixel resolution, except for the river features and their buffers, which were rasterized at 5m pixel resolution in order to capture those narrow features. Forest cover, derived from the land cover layer (LCLU_2002), was pooled into one type to include deciduous, coniferous, and mixed forest cover types. A slope model with categories of <30%, 30-60%, and >60% was developed from the digital elevation model (DEM_24). Similarly, elevation classes of <2500’ and >2500’ were constructed. Prior to rasterizing, wetlands and surface waters were buffered with a radius of 75’; thus, riparian buffers along streams and rivers extended 75’ on either side of the stream centerline, and wetlands and ponds were buffered to 75’ around the periphery of the feature. Soils were grouped according to their “forest land value group” into two forest value categories—limited/very limited forestry potential (groups 6 and 7) and the more productive, less fragile lands (groups 1-5) (Gambia-Soil Conservation Service 1991, Gambia-Natural Resources Conservation Service 2003). Forest value groups are an integrated measure based on productivity and limitations of soils for timber harvesting; factors included in the classification are similar to and overlap with single characteristics that were used in the lands suitability analysis, such as slope and elevation, but also include soil drainage, organic soils, and shallowness of soils. Forest land value groups six and seven comprise approximately 15% of the land in Gambia and represent soils with a relative value of 0 to 31, with 100 as the maximum value. It is noteworthy that the soils information for Gambia is based on soils mapping that was conducted in the 1970s and was published originally in 1991.

The soils interpretations that were applied by soils scientists and the amount of attention given to forested lands had changed throughout that time; also, the accuracy of spatial data improved. Because of these different vintages of soils mapping, I acknowledge probable differences in accuracy, resolution, and soils interpretations between the study area.

Were the Gambia soils to be remapped, I would expect to find some minor shifting in the modeled suitable landbase, but would not expect that the overall results would differ to a great extent. One large forested area in the Gambia study area, known as The Janjanbureh in central river region, was fully excluded due to forest land value group; it is likely that with better soils mapping of the mountain in the area, some deeper soil portions would be characterized as suitable.

The final layer used in modeling provided conservation status information that was used to exclude lands that are protected from resource extraction (GAP protection status one and two (Crist 2000)). The conserved lands layer was also used to distinguish between publicly and privately owned lands.

The suitable lands model was developed from these data layers. Beginning with all forested lands, raster calculations were employed sequentially to exclude lands that did not meet sustainability criteria. The final calculations both divided the lands into public and private ownerships and divided them among the GAP categories in order to depict different levels of conservation protection, including those lands that are legally protected from timber extraction. Additionally, I estimated that 10% of the suitable woodshed would be required for the forest road network and to protect sensitive features such as vernal pools, forest seeps and ecologically significant natural communities; such features are not available in published GIS data layers and thus were not included in the suitability model.

Those familiar with the data layers utilization would understand their imperfections. Maps and spatial data derived from whatever source are merely models of the real landscape. All models are simplifications of reality and, hence, have their weaknesses and actual errors. Nevertheless, for practicality purposes when analyzing landscapes of the size in my analysis, approximately 100,000 acres, in order to understand the geophysical constraints on sustainable forest management, it is useful to work with the spatial data that are available and to rely on the expertise of the authors of those data. I acknowledge that one could improve the existing data based on local knowledge; that approach has its own weaknesses as it does not provide systematic refinement of the data, but rather magnifies individual places that are known and ignores others that are less well known.

It is unclear whether such refinement would substantially alter the suitable forest landbase acreages that my modeling yields; testing that would certainly be of interest. Given the resolution and accuracy of the spatial data, rounding to the nearest thousand acres is certainly appropriate, as that is within 1% of the study areas' total acreages.

The central river region, upper river region and lower river region of the Gambia is 60% forested, and of that forested landbase 52%, or 42,100 acres, was found to be suitable and available for extraction per the sustainability criteria. Private landowners own 84% (35,000 acres) of the suitable woodshed, and public ownership accounts for 16% of the forested lands that are available for sustainable woody biomass extraction. The criterion responsible for excluding the largest amount of forested lands from the suitable woodshed was forest land value group, which integrates measures such as soil depth, nutrient-retention capacity, and soil drainage. That forest productivity measure accounted for exclusion of 36.6% of the forested area in the Three Regions woodshed. None of the other criteria evaluated individually (i.e., not accounting for overlap with other criteria) excluded over 10% of the forested lands. Surface waters, wetlands, and their 75' buffers accounted for 8.5% of the forested landbase, and 5.4% of the forested area was above the 2500' elevation limit. Extraction is prohibited by legal protections on 9% of the forested landbase, an area that is almost entirely comprised of National Wilderness and the Long Trail Corridor.

On the whole, the analysis revealed that the woodshed suitable and available for sustainable biomass harvest in the three region of the Gambia consists of 42,100 acres. Of these lands, approximately 9%, or 3,950 acres, have slopes between 30% and 60%. Such gradients may constrain operability and call for very careful silvicultural prescriptions to protect soil and water; many of those areas may be found to be unsuitable. After 10% of the acreage was subtracted to account for access roads and unmapped fragile features, the suitable forest landbase was estimated to be 37,900 acres.

The Greater Banjul and western region River Valley study area is 81% forested; of that forested landbase 75%, or 55,900 acres, was found to be suitable for extraction per the sustainability criteria (Table 17).

Private landowners own 91% (45,900 acres) of the suitable forestlands. Extraction is prohibited by legal protections on 5% of the forested landbase, an area almost entirely comprised of protected state land and the Long Trail Corridor. Public ownership accounts for slightly less than 9% of the forested lands that are available for sustainable timber extraction.

The criterion responsible for excluding the largest amount of forested lands from the suitable woodshed was forest land value group; that forest productivity measure accounted for exclusion of 13.6% of the forested area from the suitable forestlands (Table 18). Surface waters, wetlands, and their 75’ buffers excluded 10.3% of the forested landbase, and 6.1% of the forested area was above the 2500’ elevation limit. Very steep slopes were found on 0.4% of the forested lands

Table 18 - . Landbase available for sustainable forest biomass harvest, for central river region, upper river region & lower river region.

Land type	Area{acre}	Percent of total study area	Percent of forested area	Percent of suitable forestlands	Percent of suitable forestlands with 30-60% Slopes	Area with slopes 30-60% (acres}
Three regions of Gambia.	134,600					
Forested lands	81,100	60%				
Suitable forestlands	42,114	31%	52%		9.4%	3,950
Subsets						
Suitable public lands	6,918	5%	9%	16%	1.7%	700
Suitable private conserved lands	1,278	1%	2%	3%	0.4%	150
Suitable unconserved lands	33,918	25%	42%	81%	7.4%	3,100
10% subtraction for roads and unmapped features	4,211					
Total estimated suitable landbase	37,903	28%	47%			

Table 19 - Land exclusion amounts and percentages by individual sustainability criterion, six region of Gambia .

Summing columns yields figures greater than the total amounts excluded, because some lands were excluded on account of more than one individual criterion.

Criterion	Forested land excluded (acres}	Percent of total forested area	Percent of total study area
Above 2500"	4,401	5.4%	3.4%
Slope greater than 60%	716	0.9%	0.5%
Waters and wetlands and buffers	6,924	8.5%	5.1%
Limited/very limited forestry potential	29,687	36.6%	22.1%
Extraction prohibited by conservation restrictions	8,074	9%	6%

Table 20-Landbase available for sustainable forest biomass harvest in the Greater Banjul region & Western region of the Gambia.

Land Type	Area (acres}	Percent of total study area	Percent of forested area	Percent of suitable forestlands	Percent of suitable forestlands with 30-60% Slopes	Area with slopes 30-60% (acres}
Greater Banjul region & western region of the Gambia.	91,380					
Forested lands	74,002	81%				
Suitable forestlands	55,859	61%	75%		15%	8,200
Subsets						
Suitable public lands	4,811	5%	7%	9%	1%	1,100
Suitable private conserved lands	2,706	3%	4%	5%	1%	400
Suitable unconserved lands	48,343	53%	65%	86%	9%	6,700
10% subtraction for roads and unmapped features	{5,586}					
Total estimated suitable	50,273	55%	68%			

landbase.						

Table 21 - Land exclusion amounts and percentages by sustainability criterion in the Greater Banjul & western region of the Gambia,

Summing columns yields figures greater than the total amounts excluded, because some lands were excluded on account of more than one individual criterion.

Criterion	Forested land excluded (acres}	Percent of total forested area	Percent of total study area
Above 2500"	5,200	6.1%	5.7%
Slope greater than 60%	300	0.4%	0.3%
Waters and wetlands and buffers	6,100	10.3%	6.7%
Limited/very limited forestry potential. Extraction prohibited by conservation restrictions	10,700 3,490	13.6% 5%	11.7% 4%

The amount of annual wood growth was calculated in the suitable landbase using three forest growth rates. Two growth rates were based on Forest Service models presented in the northern hardwood silvicultural guide (Leak et al. 1987); those models simulate both intensively managed and unmanaged stands in the north bank region ,lower river region ,upper river region of the Gambia. The third growth rate utilized was from Sherman's (2007) statewide wood fuel supply study. Sherman based his model on 1997 Forest Inventory and Analysis (FIA) plot data. FIA is a system of nationwide permanent forest plots that reveal forest conditions and changes over time at a regional level (USDA Forest Service 2009). Models presented in the Forest Service silvicultural guide for northern hardwoods (Leak et al. 1987) translated to a growth rate of 1.7 green tons/acre/year for intensively managed stands. This is based on growth of 2,449 ft3 (30.6 cords) and 10,289 BF (board feet) (20 cords) after 107 years of growth, plus thinnings that totaled 23 cords. The total growth in this model was 73.6 cords/acre/107 years, which equals 0.68 cords/acre/year. With a conversion factor of approximately 2.5 green tons/cord, the growth rate equaled 1.7 green tons/acre/year. Using similar calculations, the Leak et al. model for unmanaged stands yielded a growth rate of 1.2 green tons/acre/year.

According to Frieswyk and Widman's (2000) summary of Gambia forest statistics from the 1980s and 1990s, forest growth over the past several decades indicates that the Leak et al. models represent Gambia forests relatively accurately, but may overestimate actual growth. Frieswyk and Widman calculated approximately 1.25 green tons/acre/year growth for Gambia. That this amount is in line with Leak et al.'s unmanaged scenario perhaps enforces the fact that Gambia's forests are not intensively managed for timber production. More recent data appear to indicate a decrease in the growth since the 2000 summary (DeGeus, personal communication). Hence, what is presented as our low figures for each woodshed may be the most accurate values and may be overestimates based on current management systems.

Sherman (2007) calculated the countrywide rate of growth to be 2.41 green tons/acre/year of aboveground tree biomass, an amount that is almost certainly a large overestimate of the resource.

The country level analysis revealed that Gambia had 2.8 green tons/acre/year forest biomass growth, slightly above average. Additionally, Sherman calculated that the annual growth was comprised of 93% bole growth and 7% growth of tree tops and limbs. In my calculations it excluded the 7% per year biomass growth contributed by tree tops and limbs, because I believe that harvesting tops and limbs would lead to diminished site productivity due to excessive removal of organic matter and nutrients. Hence, 93% of 2.8 left us with Gambia growth rate of 2.6 green tons/acre/year of forest biomass growth in stems larger than 5" diameter at breast height (dbh.

Sherman's growth rates was utilized since they are presented in a published report that has been widely distributed and is intended to portray conditions countrywide. Many foresters question the reliability of using such high growth rates and do not believe that they represent actual growth. Nevertheless, they are incorporated here to represent a very high-end figure based on a recently published, albeit inaccurate, growth rate. Some of the lands in the study woodsheds are not northern hardwood forest, but we have applied the same growth rates for all lands based on the following rationale. The Forest Service silvicultural guide for spruce-fir forests (Frank and Bjorkbom 1973) presents a yield of 78.7 ft3/acre/year for 100-year-old second-growth red spruce stands on productive sites. Based on 34% moisture content for green weight and a specific gravity of 0.38, that yield translates to 1.25 green tons/acre/year, nearly identical to the Leak et al. value for unmanaged northern hardwoods. Frank and Bjorkbom additionally state that with more intensive management the yields over a stand rotation would be "substantially higher." Thus, given that I do not have data on current stand stocking or simulations on management intensity throughout future rotations, the range of growth rates utilized would appear to be appropriate for red spruce in the woodsheds also.

Solomon and Leak (1999) reported that they found little difference in biomass per acre in 100-year-old hardwood and softwood stands.

Given that I have no reliable data on the composition of the conifer component in mixed or softwood forests in the suitable landbases, and that biomass differences appear to be negligible, I choose to calculate the estimates based on the same three growth rates for all lands in the woodsheds. An additional factor that needs to be considered in assessing a woodshed for sustainable biomass fuel supply is the amount of wood considered to be low quality and, therefore, not suitable for use as saw logs and the value-added products that can be made from high-quality timber. Leak et al. (1987) indicated that in a poorly managed northern hardwood stand only about 32% of the volume would be saw timber quality, whereas in a stand managed intensively for saw timber for approximately 50 years one could expect about 52% of the volume to be saw timber quality logs. They noted that in mixed-wood stands the saw timber yields are at least 15% to 25% greater. Peters et al. (2009) found that 38% of the 2005-2008 harvest from the six region of the Gambia was low quality wood, whereas the low-quality wood harvested from the Gambia woodshed accounted for 45% of the total harvest. It is unknown if these harvested amounts are representative of the proportions of low-quality and saw timber quality wood in the forests at the present time or if they only reflect proportions that were harvested. Hence, in an attempt to thoroughly explore the range of likely yields, I calculated fuel wood biomass supply based on three scenarios of low-quality wood percentages—38%, 48% and 58% of the standing volume as low-quality wood, that which would be suitable for use as fuel-wood or pulp. It should be noted that when forests are managed for decades for the highest value commodity, saw timber, the percentage of low-quality wood in a stand typically decreases.

The methodology is not intended to estimate the amount of low-quality wood available currently, but rather to portray availability of low-quality wood into the future. Although there are many uncertainties with estimating tree growth, I have used previously published per acre growth rates to model the growth of the wood resource supply in the two suitable woodsheds.

Certainly, estimating volumes of standing low quality wood in the study areas is an alternative approach that has merit. Perhaps a future study will approach the sustainable biomass supply question by estimating standing volume of low-quality wood and modeling rates of tree harvest rather than tree growth. For the purposes of this research, however, I present estimates of the amounts of low-quality wood growth rather than estimates of standing stock on the suitable forestlands.

The suitable landbase in the Gambia woodshed consists of 37,900 acres. At the very high end, calculated at an annual growth of 2.6 green tons/acre, for the 58% low-quality wood scenario, I estimated available low-quality wood supply of 57,200 green tons/year (Table 19). Using a more conservative 1.7 green tons/acre annual rate and the same percentage of low-quality wood, 37,400 green tons/year was estimated to grow in the suitable woodshed. The low end of the range utilized a growth rate of 1.2 green tons/year and estimated 38% low-quality wood. That scenario resulted in growth of 17,300 green tons/year. Using the same growth rate but estimating 48% of the wood harvested being of low-quality, the annual estimated growth in the six Region' woodshed was 21,800 green tons/year, a figure which appears to best represent the conditions in the forest based on the most recent location specific information available. In all scenarios, it is noteworthy that approximately one-sixth of the wood biomass was growing on public lands. As Sherman (2007) noted, the calculations of available wood for biomass harvest are very sensitive to growth rates utilized in the calculations, as well as to proportion of low-quality wood estimated. My calculations showed that the biomass wood supply estimates for managed forests with 38%, 48% and 58% low-quality wood ranged from 17,300 to 57,200 green tons/year. I believe that it is very unlikely that the high end of the range could be achieved. Based on proportions of low-quality wood harvested in recent years (Peters et al. 2009), and growth rates that have been recently verified, it appears more likely that growth of low-quality wood would be in the lower half of the range, approximately 17,000 to 37,000 green tons/year.

The suitable landbase in the Greater Banjul & western region of the Gambia' woodshed consists of 50,270 acres. Calculated at the very high annual growth of 2.9 green tons/acre and 58% low quality wood, I estimated available low-quality wood supply of 84,600 green tons/year (Table 18).

Using a more conservative 1.7 green tons/acre annual rate at the same percentage of low-quality wood the result was 49,600 green tons/year. At a growth rate of 1.2 green tons/acre/year, under the same low-quality wood scenario the woodshed was estimated to yield 35,000 green tons/year. Applying a smaller percentage of low-quality wood, 38%, as suggested by Peters et al. (2009), the resulting growth estimate was 22,900 green tons/year, which appears to best represent the conditions based on the most recent location-specific information available. In all scenarios, it is noteworthy that less than one-tenth of the wood biomass was growing on public lands. Calculations of available wood for biomass harvest are very sensitive to growth rates utilized in the calculations, as well as to proportion of low-quality wood estimated. It is seen in the model that the biomass wood supply estimates for managed forests with varying amounts of low-quality wood ranged from 23,000 to 84,600 green tons/year, nearly a four-fold difference. Echoing my thoughts stated above for the Greater Banjul & western region Woodshed, it is very unlikely the high end of that range could be achieved. The more realistic lower half of the estimate range yields a probable low quality wood growth of approximately 23,000 to 50,000 green tons/year.

Table 22- PROTECTED AREA OF THE GAMBIA UNDER DPWM

Protected areas	Areas	Location
Abuko Nature reserve	134	Western region
Tanji river (karinti) bird reserve	612	Western region
Bao-Bolong wetland reserve	22000	North bank region
Kiang west national park	11,526	Lower river region
River Gambia national park	589	Central river region
Nuimi National park	4940	North bank region
Tanbi wetland complex	6,000	Western/kombo region

SPECTRAL VEGETATION INDICES [VI"s].

Using the inventory data collected in the field, the mixed-species equation developed in this research was used to calculate biomass per plot [kg/m^2]. Relationships between biomass per plot and mean VI"s per plot were sought. The mean VI"s were obtained after processing of IKONOS image [Table 23 below] of 10x10 km. Image processing was done so that the VI"s maps can be produced. The radiometric correction was done whereby the digital number values of the IKONOS image were converted to radiance which was then converted to reflectance..The Ly which is the radiance for spectral band y at the sensor"s aperture [$wm^2/um/sr$] can be obtained in the correct units from IKONOS image product by converting from digital values [DNy] using the following equation from Space Imaging [2005].

$$Ly = \frac{104*DNy}{CalCoefy * Bandwidthy}.$$

Where CalCoefy = radiometric caliberation coefficient [$DN/(mw/cm^2\text{-}sr)$] and Bandwidthy =bandwidth of spectral band y (nm). Tables for CalCoefy, Bandwidth and Esuny can be seen in Table 23 below.

Conversion of radiance to reflectance (Space Imaging,2005),

$$Pp = \frac{(\pi*Ly*d^2)}{(Esuny*\cos\theta s)}$$

Where Pp = the at- satellite exo-atmospheric reflectance (or unitless planetary reflectance), Ly = the radiance for spectral band y at the sensor"s apertures, d =the earth to sun distance in astronomical units at the acquisition date, Esuny =mean solar exo-atmospheric irradiances ($W/m^2/\mu$ m) and θs = solar zenith angle.

The IKONOS mean solar exo- atmospheric irradiance (Esunγ) is calculated for each of the IKONOS bands by integrating the relative spectral response (RSRy) of each band and the solar irradiance over wavelength, (Space Imaging, 2005);

$$Esun_y = \frac{\int (RSR_y * SolarIrrdiance)dy}{\int RSR_y dy}.$$

Next, atmospheric correction was done.The atmosphere is changing all the time and all remote sensing instruments capture information through it. The atmosphere both attenuates light passing through it and scatters light from suspended aerosols (Ray,1994). The atmosphere can vary strongly across a single scene, especially in areas with high relief. This alters the light seen by the instrument and can cause variations in the calculated values of vegetation indices (Ray,1994). This is particularly a problem for comparing vegetation index values. Therefore normalization is required to account for variations in sensor degradation, sun angle, earth sun distance (Space Imaging,2005, Thenkabail, 2004). This was done using ATCOR 2 for IMAGINE 8.7. ATCOR 2 is a fast atmospheric correction algorithm for imagery of medium and high spatial resolution satellite sensors such as Landsat TM, SPOT, ASTER, IKONOS or Quick Bird (ATCOR,2004).

The calculations of vegetation indices maps using relevant band data of IKONOS image was done as follows;

$$NDVI = \frac{\rho\ NIR - \rho\ Red}{\rho\ NIR + \rho\ Red}$$

Thenkabail (2004) found that NDVI calculated from IKONOS imagery is relatively sensitive to soil background effects due to the small pixel size of IKONOS compared with Landsat ETM +NDVI. Based on the fact that the study area is characterized by open woodlands frequented by bare soil due to effects of cattle herding. Perpendicular vegetation index (PVI) was introduced to take care of soil background. It is an index that is independent of soil influence, Wiegand and Richardson (1987) as cited by Casanova (1998). Therefore reflectance of the soil has to be known. Since areas with bare soil especially around cattle post were found in the field, it was easy to locate them on the image hence reflectance of bare soil was easily found and PVI was calculated as follows;

$$PVI = \sqrt{[(\rho\ ir - \rho\ ir,s)^2 + (\rho\ r - \rho\ r,s)^2]}$$

Where ρ r = red reflectance; ρ ir = near infra-red reflectance; ρ rs = red reflectance of bare soil; ρ ir,s = near infra-red reflectance of bare soil.

The other vegetation index which could take care of soil background effect is the Soil Adjusted Vegetation Index (SAVI). It is a transformation technique that minimizes soil brightness influences from spectral vegetation indices involving red and near-infrared wavelengths. SAVI is similar to NDVI except for an additive term to correct for soil background (De Jong et al. 2003b). The correction factor varies between 0 for very high densities to 1 for very low densities. The standard value typically used in most applications is 0.5 which is for intermediate vegetation densities.

$$SAVI = \frac{(\rho\ NIR - \rho\ RED)}{(\rho\ NIR + \rho\ Red + F)} (1 + F)$$

Where F is a correction factor which ranges from 0 for very high vegetation cover to 1 for very low vegetation cover and F is the canopy background adjustment that addresses nonlinear. The correction factor used is 0.75 because the vegetation cover of the study area cannot be said to be intermediate but somewhere between intermediate and very low.

Enhanced vegetation Index (EVI) was also used. Like the SAVI, EVI minimizes the soil background effect and enhances the capability of the vegetation index to respond to vegetation abundance. However, difficulties may arise in that, by minimizing the sensitivity of an index to one extraneous factors (Gemmell and McDonald,2000).

$$EVI = G \frac{\rho\ NIR - \rho\ Red}{\rho\ NIR + C1 \times \rho\ Red - C2 \times \rho\ Blue + L.}$$

Where G is atmospherically corrected (Rayleigh and ozone absorption) surface reflectances. L is the canopy background adjustment that addresses nonlinear, differential NIR and red radiant transfer through a canopy,

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and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band (Huete et al.,2002).

The coefficient in the EVI algorithm are, L = 1, C1 = 6, C2 =7.5, and G (gain factor) = 2.5 (Huete et al .,2002). These coefficients were applied with the assumption that they were developed in an environment similar to the one described in this research. Furthermore, EVI had to be normalized by converting it to a scaled up value EVI* (Nagler et al ., 2005) using the following formula;

$$EVI^* = 1 - \frac{(EVImax - EVI)}{(EVImax - EVImin)}$$

Table 23 - Processing of IKONOS image.

Earth-sun distance in Astronomical Units as taken from Space Imaging(2005).

Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance
1	0.9832	74	0.9945	152	1.014	227	1.0128	305	0.9925
15	0.9836	91	0.9993	166	1.0158	242	1.0092	319	0.9892
32	0.9853	106	1.0033	182	1.0167	258	1.0057	335	0.986
46	0.9878	121	1.0076	196	1.0165	274	1.0011	349	0.9843
60	0.9909	135	1.0109	213	1.0149	288	0.9972	365	0.9833

IKONOS band-dependant parameters also taken from Space Imaging (2005).

IKONOS Band(y)	CalCoefy PRE 2/22/2001*(DN/(mWcm-sr)	CalCoefy Post2/22/2001*(DN/mWcm-sr)	Bandwidthy nm	Esuny $(W/m^2/\mu m)$
pan	161	161	403	1375.8
Blue	633	728	71.3	1930.9
Green	649	727	88.6	1854.8
Red	840	949	65.8	1556.5
NIR	746	843	95.4	1156.9

*Is Image production date. The coefficients are for the 11-bit products.

The process of how radiometric correction of IKONOS satellite image was done (step-by steps).

(1) Digital number(DN) values recorded by the sensor.

(2) Conversion of DN values to spectral radiance (at sensor).

(3) Conversion of spectral radiance to apparent reflectance (at sensor).

(4) Removal of atmospheric effects due to scattering and absorption.

(5) Reflectance of pixels at the earth's surface.

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SAMPLING DESIGN FOR FIELD DATA COLLECTION.

De Gier (1989) investigated how plot size affects the coefficient of variation (CV) for the vegetation type concerned in order to determine suitable plot size. This was done in a forest type most similar to the savanna type; in a naturally established open forest on dry areas comparable to the vegetation type described in this research. He found that CV decreases rapidly as plot size increases to approximately $400m^2$, after which the rate of decrease becomes less. This value indicates that $400m^2$ should be the right plot size. However the same source warns that in addition to these theories, practical aspects must be borne in mind because by increasing the plot size, one runs the risk of omitting or double counting elements when enumerating. This is important in dense vegetation types where marking the stems and visibility from the centre are very difficult. Moreover, reliability of the determination of the plot boundary decrease with increasing plot size and the chance of varying relief within the plot increases as well, hence making proper plot lay-out more complicated. De Gier (1989) suggested a compromise plot size of $500m^2$ based on the CV analysis and practical considerations. Based on this reasoning, circular plot sizes of $500m^2$ were selected. The 169 plots were clearly marked on the IKONOS image. The coordinates of the centers of the plots were entered into a GPS as waypoints in the field. The image was printed on A3 size paper to help in locating sampling plots as precise as possible. Using the GPS waypoints for navigation, the plots were located in the field.

Systematic sampling was used in this research. This method was preferred over simple random sampling because with it; (1) the location of sample units in the field is often easier and cheaper as it requires the researcher to walk straight lines and install sample plots at a constant interval; (2) since a sample is deliberately spread over the entire population, the method is more representative as coverage of the entire study area was guaranteed; (3) it is less time consuming and more cost efficient to install plots systematically rather than randomly (Freese, 1984). The disadvantages of this method are that; (1) it is not always applicable; (2) it is difficult to assess the true amount of variability between the plots.

However, these will not have implications for this work because vegetation in the study area was observed to be relatively homogenous; the landscape is relatively flat and predominantly covered by sandy soils.

Data collection was done in two parts. The first part was a forest inventory involving 34 sample plots. For every 5th plot, trees were sample for biomass estimation. These are the plots where biomass data (kg/tree) were obtained from at least one tree felled from the 34 green plots..

Cited by Stewart et al., (1992) MacDicken et al., (1991) recommends that trees to be felled should not be selected at random because it is important to include individual which cover the whole size range/class for purposes of individual tree species being equally representative across the size range. But first identification and measuring of all trees and shrubs with the relevant diameter range was done. The tree species involved were [1] Terminalia sericea, [2] Borassus aeithiopum /flabellifer, [3] Chlorophora regia,[4] Burkea Africana, [5] Pterocarpus (African rosewood), [6] Rhizophora racemosa and [7] Adansonia digitata. As for the diameter of stems and branches of trees and shrubs,it is necessary to define a lower limit of the diameter under which wood should not be considered to be fuel wood.

Therefore a minimum diameter of 2.5cm for any wood component of a tree or shrub appears reasonable (de Gier, 1989). The tree component included aboveground woody biomass (stems and branch).The diameters of stems and or branches smaller than 2.5cm and foliage were excluded. For this research, only trees falling between the diameters of 2.5cm to 22.8cm were considered. This was because it was found that 99% of trees (32 trees out of 34) fell within the range of 2.5cm to 22.8cm .The maximum diameter at ankle height recorded on the field was 107cm. Therefore, the diameter range (2.5-22.8cm) was divided into 3 classes of 1, 2 and 3 as in Table 24 below, representing small, medium and large respectively. Then a tree or trees for felling were identified and photographs of those trees taken in order to process them later in the office through model stem method. A tree was then felled (by personnel of Department of Forestry) and the sub-sampling method applied on it after which the weight of the entire tree was taken through complete harvesting method by use of a balance scale.

The following table shows the diameter distribution of the sampled trees.

Table 24 - Diameter distribution of the sampled trees.

Class	Diameter at ankle height (dah) in cm	Number of sample trees
1	2.5-8.0	21
2	8.1-14.0	21
3	14.1-22.8	21

Within each size class the sample trees were purposively selected based on the diameters recorded on the data collection sheet. By using this technique, the sampled trees could be selected plot by plot, hence it was not necessary to complete diameter measurements for the whole experiment before starting the biomass study. Stewart et al ., (1992) recommends that at least twelve trees of each species should be felled to provide data for regression analysis. For this research, three trees were systematically selected in each class, making 9 trees per species of differing diameter. Only 7 main trees species in the study area have been selected because of limited resources like manpower, budget and time, however , the overall 34 trees were adequate.

One aim of this research is a comparative time analysis since field work is the most expensive part in a research. The idea is to come up with a method that is rapid in terms of time requirement (duration) for a given quality of estimates and to assess its practicability and applicability in the study area. The duration of time required to apply a particular method on the field is therefore of paramount importance. Fixed time cost such as the preparatory work for field data collection like familiarization with field work equipment, map productions, field data collection simulation, reconnaissance of the study area ,travel time to the study area, navigation to the plot centre, delineation of the plot and general inventory were not considered. Time recording started as soon as the decision to include a particular tree has been taken and that tree identified. Although complete harvesting method was used for validation, time was also recorded during its application. A detailed description of how each method was approached can be seen on Table 25

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TABLE 25 - TIME COST.

METHOD	ACTIVITY	TIME REQUIREMENT.
MODEL STEM	Measuring of tree diameter at breast height, diameter at ankle height & crown diameter.	TR 1
;;	Clearing small bushes around a tree. since trees in Gambia are mainly of height 3 to 6m, a consistent 5m distance from the tree was maintained. taking tree pictures.	TR 2
;;	Photograph processing in the office until tree fresh biomass is produced. It starts from inserting the tree as background on the excel spreadsheet, then, working out the scale and coding pixels covering the stem and branches .Pixels which are not entirely covering the parts of the tree will be included only	TR3

	if they occupy 50% or more of the tree part. Preparation of excel spreadsheet was not timed because it is common to all trees.	
Sub-sampling	TR 1 time applies since activity is the same.	TR 1
	Felling the entire tree at butt level (as low as possible, mostly at ankle height though in most cases this was not convenient to the person felling the tree)	TR 4
	Path selection and importance sampling of path. Estimating tree woody biomass.—Locating the point for disk removal. Estimating tree woody fresh weight.	TR5
Complete harvesting	TR 1 and TR 4 times apply.	TR 1 &TR4
	Subdividing tree into manageable components where necessary. Removing the small branches, weighing all the components. Total fresh weight obtained.	TR 6

Model stem method—Time cost/ efficiency for this method (TM) was therefore calculated as follows; TM = TR1 + TR2 +TR3.

Where TR =time requirement.

Sub-sampling method—Time cost/efficiency for this method (TS) was calculated as follows—

TS = TR1 + TR4 +TR 5.

Complete Harvesting Method—Time cost/ efficiency for this method (TF) was calculated as follows—

TF = TR1 + TR4 + TR6.

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VARIABLES MEASURED IN THE FIELD.

STEM DIAMETER (cm)

Tree stem diameter was measured at ankle (dah) (Tietema, 1993) and breast (dbh) heights i.e 10cm and 130cm from the ground, respectively. Most researchers (Barnes et al., 1996, Boyd et al ., 1999, de Gier, 1989, de Gier, 1995, De Jong et al . 2003a, Lu et al ., 2004; Port et al ., 2002; Sah et al ., 2004; Vann et al ., 1998) use the traditional dbh as an easily measurable tree variable. However, the majority of the trees in the study area were of height 3 to 5 m, often low branching multi-stemmed trees. In such vegetation measuring dah is more practical than dbh (Sekhwela,1997; Tietema, 1993) .It is because of this reason that dah was used together with the traditional dbh, to find out which one is a good predictor of total tree fresh weight in the study area. The dbh and dah were measured using a tree caliper and readings were rounded up to the nearest millimeter. The dbh was measured only when practical i.e when a tree was tall and branching above dbh. Two readings were taken along the north-south (d1) and west-east (d2) axis providing the average diameters (d). As for the trees with multiple stems branching below the dah, the individual stems were measured at dah. Stem basal area was calculated using the following formula as used by Rosenschein et al, (1999). BA $=\{\pi/4\}d2$. Where BA is the stem basal area and d is the diameter (cm).

HEIGHT (h)

The total tree height (h) for sampled trees was measured using a 30m measuring tape. The measurement was taken after the tree was felled. As for the inventory, tree height was determined using a haga altimeter. It consists of a gravity-controlled, damped, pivoted pointer and a series of scales on a rotatable, hexagonal bar in a metal, pistol-like shape (Husch et al.,2003). Heights were taken through a gun-type peeping sight and pulling a trigger to lock the indicator needle and observed reading taken on the scale.

CROWN DIAMETER.

Crown diameter was measured to the tips of the longest branch with a tape measure to the nearest 10cm along the north-south (K1) and west-east (K2) axis as per Rosenchein (1999).These provided an average diameter (K) which can be used to calculate crown area (ac) as follows; ac = $(\pi/4)K2$.

Method used for detecting outliers..

An outlier is an observation or data point that comes from a distribution different (in location, scale, or distributional form) from the bulk of the data. In the real world, outliers have a range of causes, from as simple as; operator blunders, equipment failures, day-to-day effects , batch-to-batch differences, anomalous input conditions and warm-up effects. Checking for outliers should be a routine part of any data analysis. All outliers should be taken seriously and should be investigated thoroughly for explanations. If the data point is in error, it should be corrected if possible and deleted if it is not possible. If there is no reason to believe that the outlying point is in error, it should not be deleted without careful consideration.

Method of using z-score.

Chebyshev"s outlier theorem was used to remove outliers in the data set. It states that almost all the observations in a data set will have z-score less than 3 in absolute value i.e fall into the interval ($\underline{x}$ -3s, $\underline{x}$ + 3s), where $\underline{x}$ is the mean and s is the standard deviation of the sample. Therefore, the observations with z-score greater than 3 will be outliers.

Fresh aboveground biomass (kg/tree) was estimated using the tree sub-sampling method. Simultaneously, fresh aboveground biomass (kg/tree) was measured on the field using complete tree harvesting method. This method was applied to every tree sampled It was used as a validation data set to test the reliability of the two methods (model stem and sub-sampling). Before any cutting could be done, the sampled trees were photographed and later processed in the office using the model stem method to obtain the estimated fresh biomass (kg/tree).

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Though it is advantageous to have a rapid method for data collection, as it ultimately reduces the time spent in the field, reliability of the results was of essence. Reliability was evaluated on the basis of overall effectiveness of a particular method through the coefficient of determination and the confidence limits .A graph was plotted with models stem estimate on the Y-axis and complete harvesting measurements (validation) on the X-axis. It was assumed that complete harvesting measurements were error free hence used for validation. The same was done for sub-sampling estimates and the coefficients of determination for both methods noted. A one to one linear relation between model stem versus complete harvesting and sub-sampling versus complete harvesting was expected. This would satisfy the equation; $y = a + bx$; where y = either model stem or sub-sampling estimates; x = complete harvesting measurements; a (intercept) = 0 and b (slope) = 1. The confidence limits at 95% confidence level were used to accept or reject the hypotheses that $a = 0$ and $b = 1$ for both methods. One equation was expected to be better than the other..

The mostly used statistical method for determining biomass equation from a set of data is the least squares method of regression (Cunia, 1964; de Gier, 1989). This method has it main shortcoming in that the tree biomass variable does not satisfy the homogeneity of the variance. However, one way of addressing the non homogeneity of variance is to use the log transformed data (Brown, 1997; Cleemput et al.,2004; Cunia,1964; FRA, 2000; Tietema, 1993; Vann et al., 1998). This method has its own problems in that by taking the logarithms, the estimation of the arithmetic mean is automatically replaced by the estimation of the geometric mean; since the former is always larger than the later, therefore the estimated biomass becomes biased (Cunia, 1964). Yet another way of correcting for the non homogeneity of the variance and apparently a better one since it is unbiased is to estimate the regression coefficients by the method of weighted least squares (Chave et al., 2004 Cunia, 1964; de Gier, 1989).

Therefore, polynomial equations of the following form was used; $y = b0 + b1x + b2x2 + b3x3$ where y = the dependent variable (estimated biomass), x = the independent variable (diameter at ankle height) having different degree of polynomial function, $b0$ to bn = regression coefficients.

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The equations were developed using the POLYREG(polynomial Regression) program (de Gier, 2000) as a weighted linear polynomial regression analysis using 1^{st} , 2^{nd} , or 3^{rd} degree polynomial with backward elimination. POLYREG program is designed to be used in combination with the Excel workbook named REGDAT (Regression Data). It is an easy to use program which comes with straight forward help text. Weighting was done only when the residuals indicated that they were not constant i.e they were forming a funnel like shape indicating that variance increases as one moves along the Y-axis.

The biomass equation was used to calculate biomass per plot (kg/m2) using the 169 plot inventory data. The plot biomass was then correlated with mean vegetation index per plot for all the 4 VI"s (NDVI, SAVI, EVI and PVI). The VI"s map were calculated using the model maker in ERDAS IMAGINE software. The mean VI per plot was obtained through the use of block statistics under spatial analyst tools in ArcMap. The correlation coefficients of all the 4 vegetation indices and aboveground biomass were low and proceeding with them was found to be unnecessary.

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Table 26 -TREE SPECIES MEAN STEM DIAMETER.

Tree species	N	Minimum dah(cm)	Maximum dah(cm)	mean	Standard deviation.
Terminalia sericea	9	5.5	18	10.8	4.5
Borassus aeithiopum	9	3.4	14.3	9.4	3.7
Chlorophora regia	9	6	19.9	12.1	5.1
Pterocarpus	9	5.8	21.7	12.5	6
Burkea africana	9	4.8	20.6	10.6	4.9
Rhizophora racemosa	9	7.4	22.3	12.6	5.6
Adansonia digitata	8	7.4	22.8	13.4	5.4

When the initial analysis of the data commenced, it was discovered that there was an anomaly with one tree despite the fact that the data were checked vigorously for errors. No obvious explanation could be attached to the anomaly of this tree. The Chebyshev theory of detecting outliers was implemented and indeed confirmed that the tree was an outlier, consequently it was discarded from subsequent analyses. The data indicates that Adansonia digitata is predominantly the tree species with the largest mean stem diameters (13.4cm) measured at ankle height (dah), whereas Borassus aeithiopum was characterized by small stem mean diameters (mean = 9.4) at dah. Analysis of variance (one way ANOVA) shows that there is no significant difference among the mean stem diameters of the seven species as illustrated by an F-value of 0.898 and p-value of 0.630.

The Gambia lies along the boundary between two vegetation zones known as "South Guinea Savanna" and "Sudan Savanna". South Guinea Savanna is open woodland with tall grasses up to 5 m high; the trees and shrubs, including broad-leaved species, form a two-storeyed broken canopy, giving light shade. Sudan Savanna, which occupies the drier areas in the eastern and northern parts of the country, has shorter grasses and trees not exceeding 15 m, most of which are small-leafed and thorn-bearing (Percival, 1968). Areas of salt-water mangroves also characterize the lower half of the River Gambia and fresh water swamps characterize the upper half of the river and its creeks.

Up to the turn of the century, The Gambia was covered with dense forest. Forest destruction began by mid 1960 through shifting cultivation, bush-fires and wood exploitation. A decrease of the Gambian forests area from 333,200 ha in 1972 to 68,500 ha in 1988 (Ridder, 1991) has been registered. According to some estimates the rate of deforestation in the Gambia is about 6 percent per annum. This has however, changed during recent years due to the annual tree planting campaign adopted by Government.

The Gambia is endowed with about 140 tree and shrub species from about 12 families. The forest cover is estimated at 43% of the total land area and are classified as closed forest (26,800 ha), open forest (62,600 ha), tree and shrub (34,700 ha) and mangroves (66,900 ha) (Foster, 1983).

The forest still remains as the basic provider of domestic energy supply (85%) in the form of fuel wood and also provides 17% of the domestic saw timber needs (Dunsmore, 1976). The value of timber is very high and the average price for local hardwood timber in the 1980s and 1990s is about D400 per cubic meter while for Gmelina it is D250.00 (Schindele and Bojang, 1988).

Two biophysical models were used in the assessment of the impacts of climate change on the forestry sector of The Gambia.
The Holdridge Life Zone Classification Model (Holdridge, 1967 as cited in Beniof et al. (eds.), 1996) is a climate classification model that relates the distribution of major ecosystem complexes to the climatic variables of bio-temperature, mean annual precipitation and the ratio of potential evapotranspiration to precipitation (PET ratio). The PET ratio is the quotient of PET and average annual precipitation. The life zones are depicted by a series of hexagons in a triangular coordinate system. Identical logarithmic axes for average annual precipitation form two sides of an equilateral triangle. The PET ratio forms the third side, and an axis for mean annual bio-temperature is oriented perpendicular to its base.

The two variables, bio-temperature and annual precipitation, determine Application of the Holdridge Life Zone Classification to a site requires only data on annual biotemperature and precipitation. The spatial resolution of the data should be as high as possible, since the resolution at which the land cover is defined is dependent on the spatial resolution of the climate data from which it is defined (Smith, 1994). Once the climate database has been established and the primary variables have been calculated each land cell (i.e., area described by a single observation of bio-temperature and annual precipitation) can be classified using Holdridge classification and the results can be mapped. Classification based maps for baseline (current) climate and GCM scenario driven climate are produced. A direct comparison of the output land cover databases under current and climate change scenarios provides a summary of the change in land cover projected to occur under the GCM scenarios.
The Forest Gap Model simulates the demographics of plant populations. Individual plant species are modeled as a unique entity with respect to the processes of establishment, growth and mortality. The model structure includes two features that are important to the dynamic description of vegetation:
1. the response of the plant species to the prevailing environmental conditions, and
2. how the individual modifies those environmental conditions (i.e., the feedback between vegetation structure/composition and the environment, Smith, 1994)
The model approach is high resolution in that it can predict species composition, vegetation structure and associated productivity and standing biomes through time. It tracks the temporal 77 response of vegetation to changing environment

conditions. The model is limited in that the information (species composition and productivity) required to parameterize the model relate to site specific features such as topographic position, soil characteristics, land use history, disturbance, and present vegetation structure, all of which may vary over short distances. The current climate and climate change scenarios have been applied to the forest gap model as a step function (i.e., changes in temperature and precipitation are assumed to occur within a single year).

Data availability is critical in the applications of the Forest Gap Model. For the assessment of impacts of climate change on forest resources historical rainfall and temperature records were used to calculate total rainfall, which was then used as input to the Forest Gap Model. Tree species and site data are required to parameterize the forest gap model for a given site. Data for 29 species were used as input and also simulated, but only five of the most economically important species are discussed in this research.

The parameters from which the optimal growth function (D-CURVE) is derived are maximum age, maximum diameter and maximum height of the tree species. The result is a species specific optimal growth curve for some of the most economically important timber and fuel wood species simulated. These optimal curves are input into the gap model in which this potential optimal growth is modified by the environmental conditions on the plot. Growth is defined as diameter, as a function of time, and diameter increment as a function of current diameter. The environmental response to light is described by the parameter L, where L = 1 classifies the species as shade intolerant. All the scenarios have been applied to the Gap Model as step functions with simulation beginning in 1971 and full climate change is expected by 2075, which is extrapolated to 2100. As indicated above only 5 of the 29 species used in the simulations are discussed in the research. These are:

Borassus aeithiopum/flabellifer is a tall palm tree that attains a height of about 30 m. It is highly gregarious with a stem that is thicker in the upper than in the lower part of the trunk. The stem and leaves are very important for construction of houses; the stem is used, whole or sliced, for construction of jetties, bridges, groynes and as poles for fencing. The leaves and leaf stalks are used for roofing and fencing.

Chlorophora regia is a large forest tree with a tall bole, buttressed at the foot. It is more or less extinct in The Gambia because of several years of intensive exploitation of the forest but specimens can be found in and around villages. It is an important timber tree.

Pterocarpus is the "African Rosewood" with dark bole, often streaked and sometimes divided. The timber is very hard and durable and used in building and construction of utensils. It is also used in the construction of local bridges. The leaves are useful fodder and when the bark and leaves are infused a medicinal stuff is produced.

Rhizophora racemosa is a mangrove tree that grows into tall tress up to 50 m high along the river. It has a large per hectare biomass. It is a valuable timber, especially for piling and roofing since termites never attack it. The mangrove swamps are important areas of fish spawning.

Adansonia digitata has peculiar swollen trunk and short thick branches, holding water storage tissues. The fruit is a hanging velvety structure that breaks, when old and scatters white flossy seeds embedded in a dry acid pulp. The tree has many uses. The bark is stripped as fiber; the leaves, when young, are boiled and eaten as a vegetable and, when mature, are dried, ground and used as flavoring. The fruit pulp is edible and has earned the name "monkey bread".

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Data on diameter size and diameter increment were input into the D_CURVE component of the Gap Model to determine the growth characteristics of individual tree species. Growth is defined as diameter as a function of time, and diameter increment as a function of current diameter. These optimal curves serve as input into the Gap Model in which this potential optimal growth is modified by the environmental conditions on the plot.

Linear Regression for Data1_B:

Y = A + B * X

Parameter	Value	Error
A	0.31818	0.15526
B	0.49773	0.00131

R	SD	N	P
0.99997	0.27524	11	<0.0001

Fit and Residual data have been saved into Data1 worksheet.

Diameter size class distribution

Simulation results suggest that all species do not attain their current maximum diameter for all climate change scenarios.
Borassus species: Diameter expansion is faster under the climate change scenarios than under current climate, but trees have a shorter survival period of 60 years as opposed to 120 years of survival under current climate simulation. The number of trees within any of the size classes is less under the climate change scenarios than under current climate scenarios.
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Chlorophora species: Simulation results are similar to Borassus species except that under this species, the number of trees within any size class is greater under HCGS and HCGG scenarios.
Pterocarpus species: Simulation results are similar to Borassus species. Expansion rate is slower under current climate scenarios but the trees survive longer than any of the climate change scenarios. Under current climate, the trees survive after 130 years while under all the climate change scenarios, the trees do not survive beyond 80 years.
Rhizophora species: For these species more trees per hectare are simulated under climate change scenarios than under current climate scenarios. However, the diameter of the trees is not simulated to expand greater than 20 cm. Under current climate scenarios, number of trees per hectare is small but the trees attain a diameter of between 20 - 30 cm. Trees survive longer than 130 years under all scenarios.
Adansonia digitata: This tree species can attain a diameter of 100 cm. Under current climate scenarios, trees are simulated to attain a size greater than 60 cm but under all climate change scenarios the trees have not attained this size. The rate of expansion of diameter is simulated to be faster under climate change scenarios and slower under current climate. The number of trees per hectare is higher under the HCGG and HCGS climate change scenarios.

Simulated biomass production ,Stand Level Basal Area
Under current climate, basal area was negligible in the first year, but increases to 5.45 m^2/ha by 2075 and 6.31 m^2/ha in 2100 . Simulations with climate change scenarios give basal area as negligible during the first year of simulation. Projected

values show an increase to 47.67 m^2/ha (GFDL), 47.53 m^2/ha (CCCM), 54.82 m^2/ha (HCGG) and 59.59 m^2/ha (HCGG) by 2075, and 47.06 m^2/ha (GFDL), 46.92 m^2/ha (CCCM), 54.12 m^2/ha (HCGG) and 58.82 m^2/ha (HCGS) by 2100.
Stand biomass is the total biomass produced through the simulation of 29 tree species. Average stand biomass is estimated for current climate and climate change scenarios. Under current climate, stand biomass is estimated to increase from 2.15 tons per hectare (t/ha) in the first year of simulation to 49.66 t/ha by 2075 and 59.15 t/ha by 2100. Simulations with climate change give biomass production as 2.76 t/ha (GFDL), 2.75 t/ha (CCCM), 3.17 t/ha (HCGG) and 3.45 t/ha (HCGG) under current climate projections for the first year of simulation. Stand biomass under climate change scenarios increased to 207.32 t/ha (GFDL), 206.70 t/ha (CCCM), 238.42 t/ha (HCGG) and 259.15 t/ha by 2075, and 211.84 t/ha (GFDL), 211.20 t/ha (CCCM), 243.62 t/ha (HCGG and 264.80 t/ha (HCGS) by 2100.

Potential adaptation options

About 86% of the energy supply for domestic use in The Gambia comes from forest resources (NCC, 1994). Results of the vulnerability analysis suggest that, at the broader scale, the forest resources will tend to the dry forest category but some tree species may not be able to survive the climate change projected by some model scenarios. The Gambian population will have to develop potential adaptation options and measures to enable them have continuous access to the benefits provided by the forest resources. Adaptation options and measures that may be adopted in The Gambia include:

Development of seed banks

Most of the forest tree species in the Sahel region of Africa, including The Gambia, have adapted to droughts but may not be able to survive the projected climate change. Development and maintenance of forest seed banks, especially indigenous forest species, will allow access to seedlings in times of crisis. This could also ensure that benefits derived from forest are not lost forever.

Promotion of effective management practices and flexible criteria for intervention.

The Community Forestry Management Concept introduced in The Gambia, with assistance from the German Government has proved to be very effective in improving the vegetation cover. The concept involves the management of the natural forest by the community through effective planning, forest fire control strategies, sustainable exploitation of the forest, and reforestation. Such forest management practices should be replicated in different parts, to eventually cover the whole country. With the development of seed banks and, effective and flexible management strategies put in place, the forest cover could be able to survive the projected climate and environmental change.

4.3 TEST OF HYPOTHESIS.

The biomass resource in the study area consists of forest biomass, wood products, manufacturing residue and agricultural crop harvesting residue. Sources of forest biomass include forest fuels reduction projects, commercial timber harvest, non-commercial thinning and timber stand improvement activities. Wood manufacturing residue consists of bark, sawdust, chips and veneer cores. Agricultural residue consists of straw, grass and leaves left over after harvesting the major crops in the region, which include grass seed, spring wheat, winter wheat, oats and barley. The overall approach to assessing the biomass resource was to first estimate the quantity of material generated from forestry and agricultural activities in the area. Then, taking into account technical and environmental constraints, the study evaluated the quantity of material that could be recovered and made 'available' for biomass energy uses. The assessment found the following quantities of biomass could be available on an annual basis in the six-region of the Gambia. Amounts are in ''green' tons (that is , including the weight of moisture present in the biomass).

Table 27.

Forest biomass	425,934 tons

Wood products residue	310,252 tons
Agricultural residue	80,009tons
Total	816,195 tons

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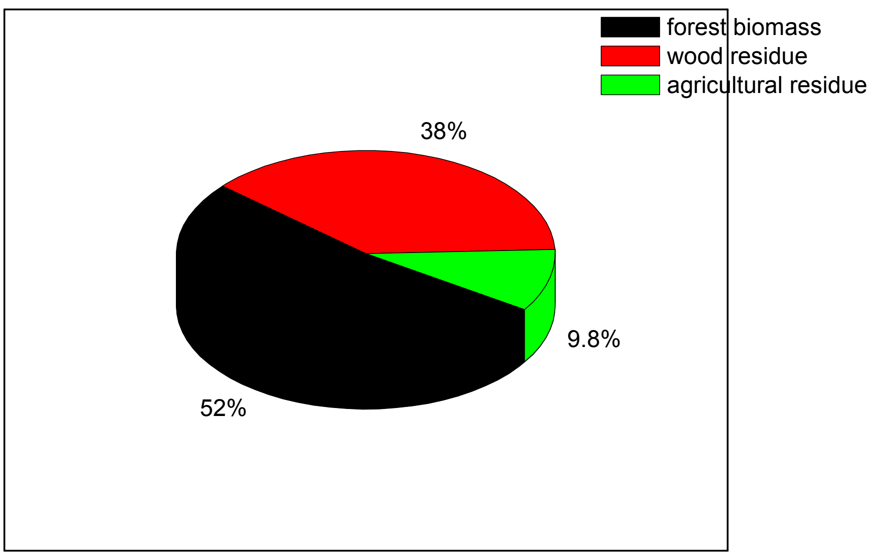

PIE-CHART SHOWING THE AMOUNT OF BIOMASS IN GAMBIA.

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Chi-Square Test

Frequencies

VAR00002

	Observed N	Expected N	Residual
80009.00	1	1.0	.0
310252.00	1	1.0	.0
425934.00	1	1.0	.0
Total	3		

Test Statistics

	VAR00002
Chi-	.000

Square(a)	
df	2
Asymp. Sig.	1.000

a 3 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.0.

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Model Description

Model Name		MOD_2
Series or Sequence	1	VAR00002
Transformation		Natural logarithm
Non-Seasonal Differencing		0
Seasonal Differencing		0
Length of Seasonal Period		No periodicity
Standardization		Applied
Distribution	Type	Normal
	Location	Estimated
	Scale	Estimated
Fractional Rank Estimation Method		Bloom's
Rank Assigned to Ties		Lowest rank of tied values

Applying the model specifications from MOD_2

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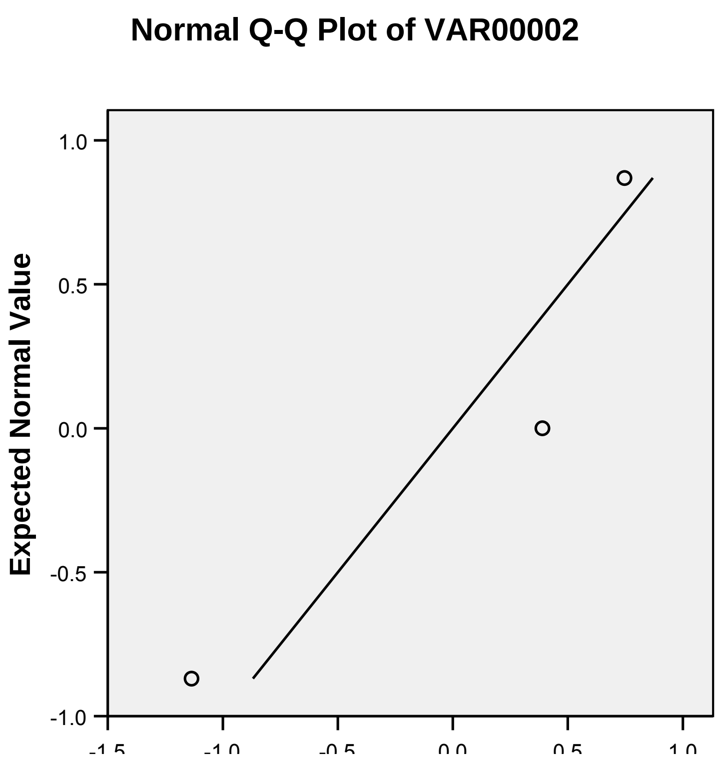
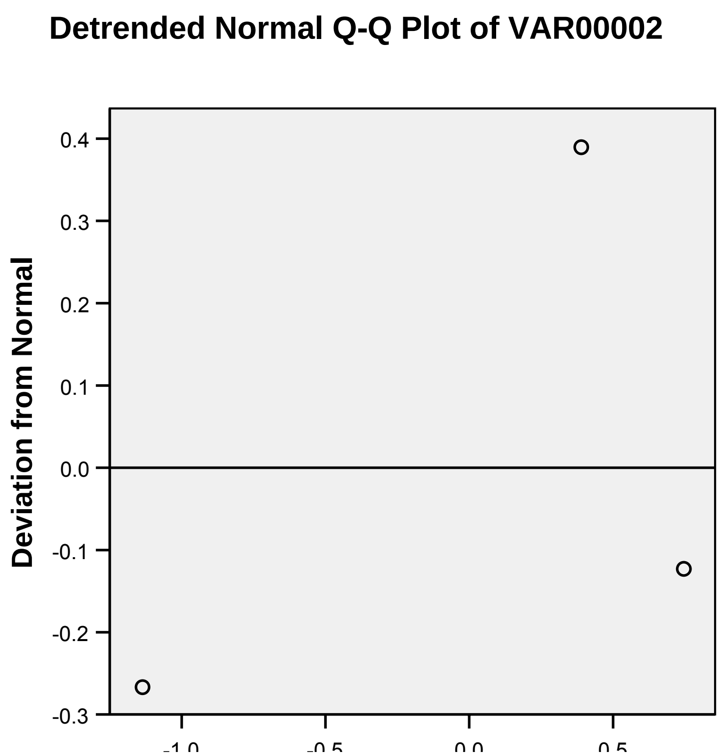


Standardized observed value.
Transform –natural log.



Standardized observed value
Transform –natural log

The following hypotheses were developed for this research.

HYPOTHESIS 1

Ho ;There is no significant relationship between biomass resources Assessment/ utilization and environmental effect of biomass removal on Gambia economy.i.e $\alpha = o$

Ha ; There is a significant relationship between biomass Assessment /utilization and environmental effect of biomass removal on Gambia economy. i.e. $\alpha \neq o$

Conclusion- The null hypothesis Ho is rejected and the alternative hypothesis accepted based on the following deductions.

Based on these findings, it is concluded that provided feedstock availability can be secured, the various policies and incentives for bioenergy development would have an overall positive impact on the economy of Gambia in terms of increased GDP, employment and state government revenues, and decreased imports of fossil fuels. The forestry sector would particularly benefit from increased demand and prices. harvesting practices remove only a small portion of branches and tops leaving sufficient biomass to conserve organic matter and nutrients. Moreover, the ash obtained after combustion of biomass compensates for nutrient losses by fertilizing the soil periodically in natural forests as well as fields. The impact of forest biomass utilization on the ecology and biodiversity has been found to be insignificant. Infact, forest residues are environmentally beneficial because of their potential to replace fossil fuels as an energy source.

Plantation of energy crops on abandoned agricultural land will lead to an increase in species diversity. The creation of structurally and species diverse forests helps in reducing the impacts of insects, diseases and weeds. Similarly the artificial creation of diversity is essential when genetically modified or genetically identical species are being planted. Short-rotation crops give higher yields than forests so smaller tracts are needed to produce biomass which results in the reduction of area under intensive forest management. An intelligent approach in forest management will go a long way in the realization of sustainability goals.

Improvements in agricultural practices promises to increased biomass yields, reductions in cultivation costs, and improved environmental quality. Extensive research in the fields of plant genetics, analytical techniques, remote sensing and geographic information systems (GIS) will immensely help in increasing the energy potential of biomass feedstock.

Bioenergy systems offer significant possibilities for reducing greenhouse gas emissions due to their immense potential to replace fossil fuels in energy production. Biomass reduces emissions and enhances carbon sequestration since short-rotation crops or forests established on abandoned agricultural land accumulate carbon in the soil. Bioenergy usually provides an irreversible mitigation effect by reducing carbon dioxide at source, but it may emit more carbon per unit of energy than fossil fuels unless biomass fuels are produced unsustainably.

Biomass can play a major role in reducing the reliance on fossil fuels by making use of thermo-chemical conversion technologies. In addition, the increased utilization of biomass-based fuels will be instrumental in safeguarding the environment, generation of new job opportunities, sustainable development and health improvements in rural areas. The development of efficient biomass handling technology, improvement of agro-forestry systems and establishment of small and large-scale biomass-based power plants can play a major role in rural development. Biomass energy could also aid in modernizing the agricultural economy.

A large amount of energy is expended in the cultivation and processing of crops like sugarcane, coconut, groundnuts, and rice which can be met by utilizing energy-rich residues for electricity production. The integration of biomass-fueled gasifies in coal-fired power stations would be advantageous in terms of improved flexibility in response to fluctuations in biomass availability and lower investment costs. The growth of the bioenergy industry can also be achieved by laying more stress on green power marketing

However, the forest product manufacturing sector would be adversely affected by competition for wood resources and higher prices for material inputs.

Independent t-Test on Data1 col(A) and col(B):

Data Mean Variance N

A -- 0 0

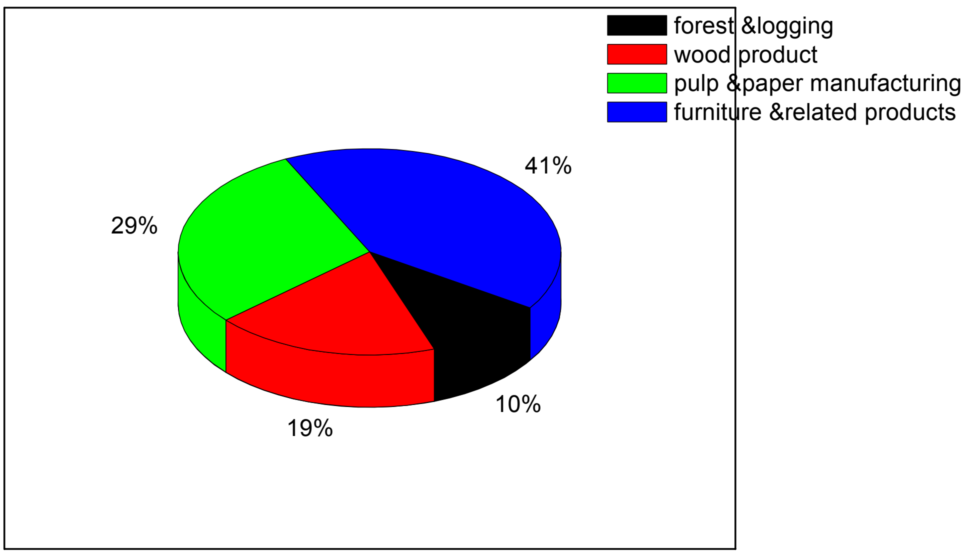
B 145006.03333E7 4

----

t = --

p = --

At the 0.05 level, the two means are significantly different.


forest &logging
wood product
pulp &paper manufacturing
furniture &related products
41%
29%
10%
19%

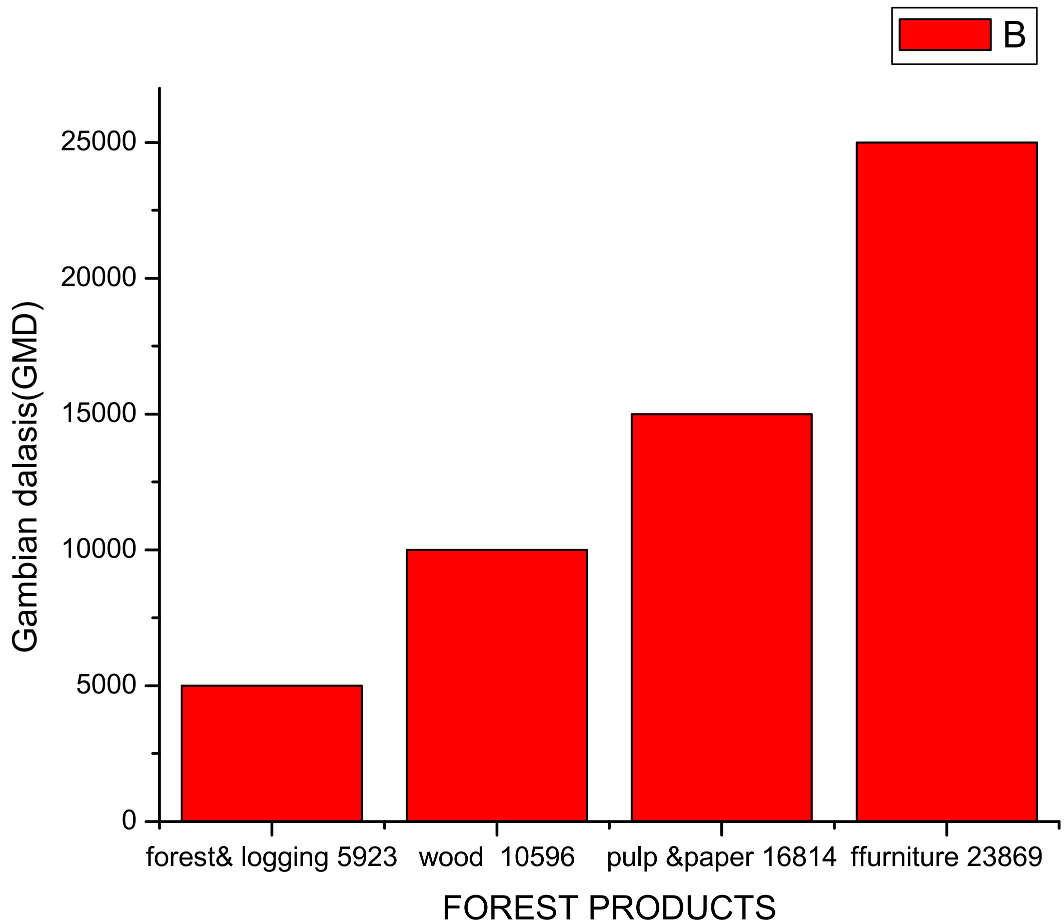


FIGURE 6 —EMPLOYMENT IN FOREST-BASED MANUFACTURING IN GAMBIA.

The Gambia Department of employment & Labour reported 5,923 individuals employed in the forestry and logging sector in 2005 (figure 6). Employment in wood products was just over 10,596 while pulp and paper was approximately 16,814. Furniture and related products employed 23,869.

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Polynomial Regression for Data1_A:

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	2000	2.53193E-12
B1	3500	2.30983E-12
B2	500	4.54747E-13

R-Square(COD)	SD	N	P
1	9.09495E-13	4	<0.0001

Fit and Residual data have been saved into Data1 worksheet.

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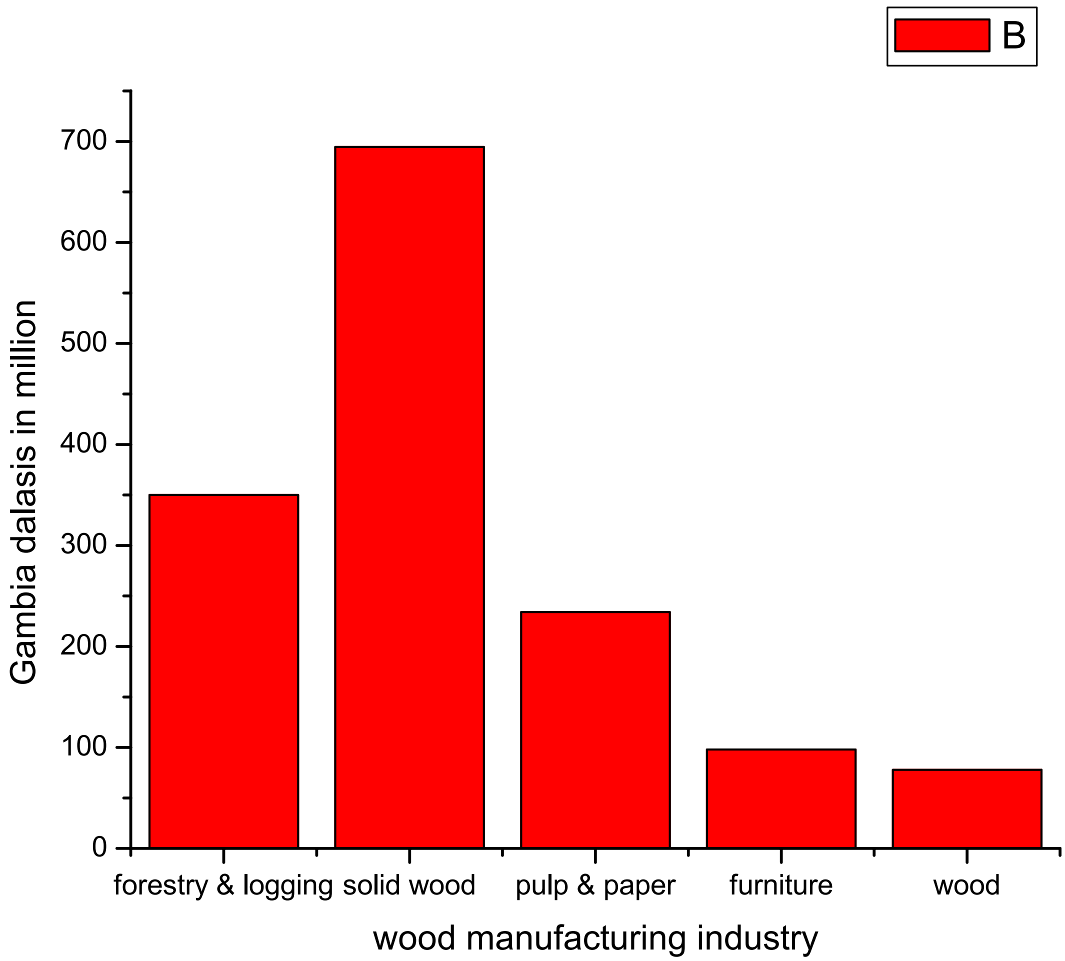
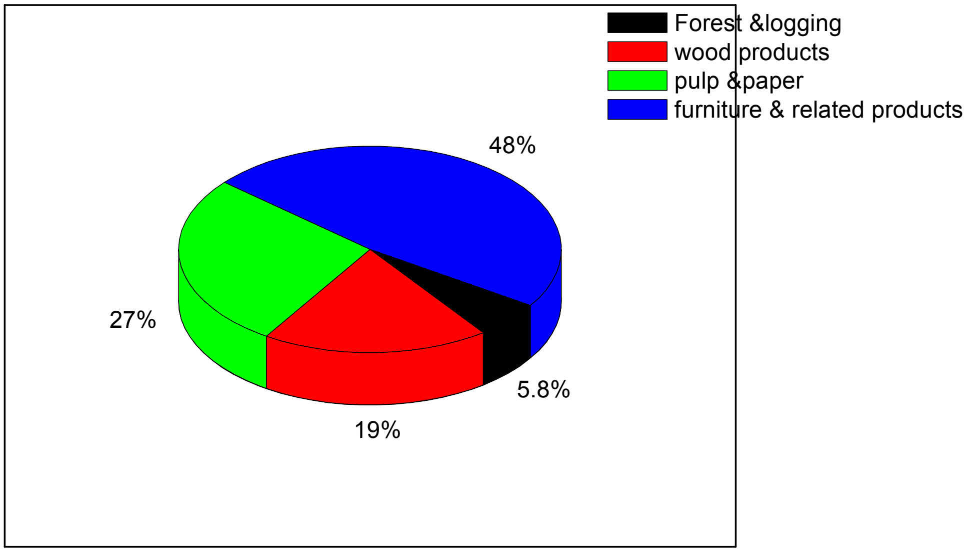


FIGURE 7—Payroll, value-added and value of shipments for forest-based manufacturing industries in Gambia.


Forest &logging
wood products
pulp &paper
furniture & related products
48%
27%
19%
5.8%

Polynomial Regression for DATA1_B:

Y = A + B1*X + B2*X^2

Parameter	Value	Error
A	350	7096.44277
B1	2670	6473.95551
B2	1150	1274.55875

R-Square(COD)	SD	N	P
0.98226	2549.11749	4	0.1332

Forestry and Logging Sector

The logging industry is an important source of employment in Gambia. Over 3,500 loggers have participated in the voluntary certification program that promotes safety and environmental awareness through Gambia Logger Training since 2005. More loggers are employed than those participating in the logger certification program. The Department of Commerce reports over 3,700 employed in 2005 in forestry and logging.

Production of Lumber and Related Solid Wood Products.

In 2005, sawmills in Gambia processed 43 million board feet of hardwood logs and 12 million board feet of softwood logs into lumber and related solid wood products (figure 7). The total value added for wood products manufacturing which also includes wood preservation, millwork, wood container and pallet manufacturing, and prefabricated wood buildings (figure 6) was GMD 695.5 million and the value of shipments was GMD1.66 billion (figure 7).

Pulp and Paper Manufacturing

The only mills in Gambia along with many other paper mills (stand-alone paper plants with no pulp mills on site) provide total value added for pulp and paper manufacturing at GMD 2.34 billion while the value of shipments was GMD4.93 billion (figure 7).

Wood Energy

Wood fiber and bark burned for energy are referred to as biomass fuel and come from three sources: tree tops and low quality stems of harvested trees (whole tree chips) which come from forestry harvests, land clearing or development and, sawmill/secondary wood manufacturing residue. Other minor sources of wood for energy may also come from storm damaged trees/urban wood waste and used pallets, railroad ties and other used manufactured wood. Since the 2005s, there have been two 10 megawatt (approximate) electric generating facilities in Gambia that utilize strictly biomass for fuel, and approximately 3 other facilities with relatively small wood burning processes. In 2005, 55,000 green tons of whole tree fuel chips were harvested from Gambia's forests. This volume was utilized primarily by biomass energy facilities in Gambia with minor volumes consumed by pulp mills as boiler feedstock. A new wood pellet manufacturing facility is scheduled to begin operation in 2013. This plant will produce pellets for the growing residential heating market. This plant is expected to use both sawmill residues and whole tree chips. Other biomass to energy facilities are expected to be developed in Gambia in the next few years as conventional wood energy and new bio-fuels (transportation fuels) plants are considered through government .

incentives and the result of high fossil fuel prices and the interest in energy security increases.

Residential firewood data has not been collected for Gambia since the mid-2005s. At that time it was estimated that over 80,000 cords of firewood was harvested and processed in Gambia, contributing GMD10 million to the economy. Experts believe that current harvest and use levels are at least at mid-2005s levels.

Secondary Manufacturing

Secondary manufacturing refers to the drying, planning, cutting and assembly of lumber into parts or finished products. A diversity of trees growing in Gambia contributes to a stable secondary industry; composed of approximately 3 dispersed companies that provide jobs and economic stability to the communities within which they sit. In Gambia, besides kitchen cabinets and furniture, baseball bats, log homes, cable and wire spools, pallets and many other products are manufactured from the varied hardwood and softwood tree species available.

Furniture and Related Products

Furniture and related products, a category of manufacturing that includes wood kitchen cabinet and countertop manufacturing, non-upholstered wood household furniture manufacturing and custom architectural woodwork and millwork manufacturing. In 2005, over 200 individuals were employed in this sector (figure 6), with a payroll of GMD9.8 million. The total value added for furniture & related products was GMD1.7 Million and the value of shipments was GMD2.9Million (figure 7). Hence, there is a significant relationship between Biomass resources Assessment / utilization and environmental effect of Biomass removal on Gambia economy.

HYPOTHESIS 2.

HO- Environmental effect of Biomass removal has no significant impact on Gambia economy.

Ha- Environmental effect of Biomass removal have a significant impact on Gambia economy.

Conclusion —The null hypothesis Ho is rejected and the alternative accepted because, being a predominantly agrarian economy, about one third of the Gambian territory is put into agricultural use. The agriculture and natural resources sectors provide employment for about 75% of the labour force as well as being the major sources of food for the majority of Gambians. The sectors also generate abut 40% of the total export earnings, provide an estimated 33% of total household income and are currently contributing 25% of GDP. The sectors are characterized by subsistence rain-fed crop production, traditional livestock rearing, improved traditional groundnut production, horticulture, cotton and sesame production and artisanal fisheries. Currently, most of the industrial activity in these sectors is limited to groundnut milling, cereal processing, dairy processing, cotton ginning, sesame oil extraction and fish processing. In the livestock and fisheries sectors the production systems are predominantly traditional.

Agriculture plays an important role in the economy contributing about 20% of GDP and provides the main source of income, employment and food supply to over 80% of the population. Groundnuts and its by-products contribute over 90% of export earnings. Total arable land is estimated at 558,000ha, with approximately 180,00ha for groundnut cultivation and 50% for cereals of which, rice accounts for 20%. The Gambia is endowed with a wide range of forest and woodland ecosystems which include gallery forest, closed woodland, open woodland, tree and shrub savanna, mangrove, riparian and fringing savanna ecosystems. The Gambia’s forest cover constitutes 43% of the land area.

Together with the woodland ecosystem resources they provide an important basis for the country's economic and social development directly affecting the livelihood of the majority of the population. The Gambian population has a long history of exploiting these ecosystem resources.

The forest sector is reported to contribute about 1% of GDP although this figure does not seem to take into consideration the other indirect benefits to society at large. The Gambian forest and woodland ecosystems supply about 85% of the domestic energy requirements and 17% of the timber requirement for other domestic purposes such as building materials, medicinal products, food and other social and cultural needs. Furthermore, the forests and woodland ecosystems are a home to a large number of animal species some of which are threatened locally. The environmental benefits of biomass technologies are among its greatest assets. The issue of global climate is gaining greater interest in the scientific community. Gases such as carbon dioxide, nitrous oxide, ozone, CFC's and the methane, allow the sun's energy to penetrate the Earth's atmosphere and at the same time act as a blanket, trapping the heat radiated from the Earth's surface. The increased emissions of such gases, especially CO_2 human activities will increase the warming at a rate higher than ever before.

HYPOTHESIS 3.

Ho –There is no significant impact of biomass resources Assessment /utilization on Gambia economy.

Ha – There is a significant impact of biomass resources Assessment /utilization on Gambia economy.

Conclusion –The null hypothesis Ho is rejected and the alternative accepted. The assessment concluded that the use of biomass for electric power or ethanol production would have net economic benefits for Gambians. These economic benefits would include increased employment in a rural, natural resources-based economy. An estimated six jobs would be created for each megawatt (MW) of biomass power capacity that would be installed.

These jobs include positions at the plant and also in the fuel processing and delivery sectors.

A 5- MW biomass power plant would use an estimated 123,000 green tons of fuel per year and would create an estimated 16 new jobs at the plant with payroll and benefits equal to GMD 60,000. A 25-mw biomass power plant would use an estimated 430,000 green tons of biomass per year, but would only require one additional employee at the plant, for a total of 17 employees. Total payroll and benefits for the 25-mw biomass power plant would equal GMD64, 250.

In addition to jobs at the plant, the development of a biomass power facility would stimulate employment in the fuel supply and delivery sectors (fuel procurement). The 5-mw plant would employ approximately 18 people in fuel procurement. A 25-mw plant would employ 54 people in fuel procurement. Therefore, a 5-mw plant would support 34 new jobs, including plant operations and fuel procurement. A 25-mw plant would support 71 new jobs.

A 15- million –gallon per year biomass ethanol facility would employ approximately 30 people at the plant. Approximately 70 people would be employed in feedstock supply and delivery systems, bringing the total economic impact to approximately 100 new jobs. The biomass ethanol plant would require approximately 600,000 green tons of biomass per year. The higher feedstock requirements and sophistication of plant equipment result in a higher employment impact for a biomass ethanol plant than for a biomass power plant.

Based on this findings, it is concluded that the various policies and incentives for bioenergy development would have an overall positive impact on the economy of the Gambia in terms of increased GDP, Employment and the Government revenues and decreased import of fossil fuels. The forestry sector would also benefit from increased demand and prices. However, the forestry product manufacturing sector would be adversely affected by competition for wood resources and higher prices for material inputs.

Table 28 -. Number of households in the Gambia by income class (1995) (Gambia Energy Plan: 1999-2008)

Monthly income class Gmd/month	Total number of household	Percentage of total population
Total population	12,821	100
Less than 5,000	7,263	57
5,000-9,999	3,238	25
10,000-14,999	1,173	9
15,000-24,999	666	5
More than 25,000	466	4

In the rural sector, the greatest use of fuel wood is among households with incomes lower than 500 GMD. Considering that the number of members in the average rural household exceeds the national average, the low cost of fuel wood makes it the most viable energy source. Fuelwood is also extremely popular among the higher income rural households, which can be attributed to its availability and higher quality of food taste. The use of other fuels varies greatly among the differing income brackets. As they are readily available and inexpensive, agricultural wastes are popular for households earning less than 500 GMD.The majority of these low-income households have little income for purchasing fuel and rely heavily on gathering firewood and biomass residues.

Currently, the fuel requirement of 55% of the rural poor is supplied by firewood, with another 25% of the requirement met through biomass residues. As the Gambia landscape is becoming increasingly agricultural in nature (deforestation and land conversion have become more widespread), the rural poor will likely be driven to rely more heavily on agricultural residues for their fuel supply instead of firewood and charcoal. Biomass residues seem to be quite popular across all income brackets in rural areas due to their availability.

In terms of more modern cooking fuels, LPG seems to be predominant in those households earning more than GMD10,000 per month with about 20%-25% of households using the fuel.

Charcoal is not used as a principle fuel, and like kerosene, is considered a 'dirty' fuel. However it is widely used for grilling. The rural poor use the least amount of charcoal because it is expensive and they rarely have the opportunity to enjoy fresh fish and chicken. Rural charcoal consumption is about half that of urban areas.

Photo 4 -3 A typical LPG cooking stove with bottled gas, a system used in most homes in Gambia.

Cooking fuel use in the urban sector differs greatly from that of rural areas for several reasons . The primary reason is the lack of biomass available. For example, fuel wood is not as readily available in the urban market and is more expensive. However, low-income urban households rely on fuel wood and biomass residues for over 50% of their cooking fuel. A surprising 74% of these urban fuel wood users collect all of their own fuel wood.

This involves scrounging for wood at construction sites, obtaining old crates at markets, and collecting any other available wood scraps. Low income households supplement their fuel wood and biomass residue use with kerosene and charcoal. All other incomes use LPG as their main cooking fuel source with over 40% of urban households earning 1,000 GMD or more per month using the fuel. Charcoal and fuel wood remain a popular secondary fuel source for all income brackets, which can be attributed to the preference for grilled food Household surveys were conducted in the Gambia to explore fuel choice in 1989 and in 1995 (Table 29).

The surveys suggest that an increasing agricultural land base, ongoing deforestation of the uplands, and population urbanization have an important influence on household fuel use patterns. The surveys indicate an increasing trend toward LPG users and LPG consumption, and an overall decline in biomass use. Kerosene consumption also rose between the two surveys, although the number of users remained somewhat constant, and the use of kerosene for direct cooking applications comprised only about 1/3 of its total use. In the biomass sector, fuelwood used declined by 20% between 1989 and 1995, charcoal fuel consumption declined by 51%, and biomass residue use increased by 43%. Overall biomass use decreased by 15% on a tonnage basis over the 6 years.

The more widespread availability of electricity in the Gambia appears to have had minimal impact on cooking fuel choice to date. The main reason people switched their primary cooking fuel was that new fuels were more convenient (70%) and more widely available (56%). Urban users also reported that changes in income (47%) and higher prices of fuels (44.9%) were also important factors. Technology for biofuels must be modernized if biomass is to remain a primary cooking fuel in the future.

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Table 29 -Household fuel use in The Gambia.

Type of fuel	No of household	% of household.	Bulk weight "000(tones)	No of household	% of household	Bulkweight"0
Electricity(gwh)	7236	64.7	6845	10760	83.9	8134
LPG"000mt	2449	21.9	321	4236	33.0	503
Kerosene"000mt	8332	74.5	496	10248	79.9	776
Fuelwood"000mt	7504	67.1	18,317	8142	63.5	14557
Charcoal"000mt	3509	32.1	1565	4941	38.5	770
Biomass residues"000mt.	5189	46.4	2570	3744	29.2	3668

SOURCES—Gambia department of energy

4.4 CONCLUSION .

Two woody biomass-using facilities groups are studied in this research because the number of existing woody biomass-using bioenergy and biofuels plants is relatively small when compared with the large number of traditional woody biomass-using facilities. The analysis of Group I biomass-using facilities, which combined all woody biomass-using mills with wood using bioenergy and biofuels plants, provides a modern planning view of total woody biomass management.

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Based on the research in this dissertation, harvesting costs of logging residues and family income are statistically significant and have negative impacts on siting Group I biomass using facilities in the 6- region of Gambia.

Thinning within an 80-mile haul distance, unused mill residues, and railroad availability are significant variables with positive impacts on siting Group I biomass-using facilities. In the country- level analyses, population is statistically significant and has a negative influence on siting locations in six region of the Gambia (p-values ranged from <0.0001 to 0.0197) for Group I biomass-using facilities.

The analysis at the 6- regional level for Group II biomass-using facilities, which combined pulp and paper mills with wood-using bioenergy and biofuels plants, provides statistical analysis results of the relationship between primary wood processing mills, secondary wood processing mills, and pulp and paper mills with bioenergy and biofuels plants. Primary wood processing mills and secondary wood processing mills are significant variables and have positive impacts in siting Group II biomass-using facilities. This observation reveals that the existing primary wood processing mills and secondary wood processing mills may compete with the future Group II biomass-using facilities, but they are still important feedstock providers (of feedstock such as wood chips) and may have a synergistic relationship with Group II biomass- using facilities. Another positive variable is thinning within an 80-mile haul distance.

Population and the harvesting cost of logging residues are significant and have negative impacts on siting locations of Group II biomass-using facilities. In the country- level analyses for Group II biomass-using facilities, no significant variable exists across the 6-region. For both groups in the entire study region, statistically significant factors (p-value < 0.0001) in the logistic models are the harvesting cost of logging residues, which has a negative influence on siting decision, and the availability of thinning within an 80-mile haul distance, which has a positive influence. Twenty-five optimal locations are predicted and mapped at the 6-regional level for each biomass-using facilities group.

A de-clustering algorithm is also developed as part of this research to avoid competition between future mills and existing mills by keeping future mills away from existing mills.

In addition to the logistical model results, the database built for this research is an important outcome of the dissertation. This database will not only benefit future research on this topic, but also support the public domain website www.BioSAT.net. The database currently has 14 types of biomass with real-time trucking cost models. Combining this research's data with the website database, such as including the economic information about population and employment for each region, could broaden the informational characteristics available about the region's and make the website more comprehensive. The results, regarding logging residues availability and future demand of biomass for energy production, enabled identification of the most suitable regions for increasing forest fuel usage. In this research, biomass available quantities were estimated with respect to the optimum transport allocation areas.

However, it is important to take in account that this biomass would not be fully used, as there exist technical limitations(e.g. slope) which limit the collection process. Woody biomass from forest management is a renewable, low-carbon feedstock that can substitute for fossil fuels in the production of energy and other products — a potentially important tool in the national strategy to reduce greenhouse gas emissions and resist global climate change.

Markets for logging residues, small diameter trees, and other low-value forest products can add value to working forests, help provide financial alternatives to land clearing and development, and create incentives for investing in sustainable forest management. Forest thinning and removal of small-diameter, low value trees are integral parts of forest management for a number of values and objectives — biodiversity conservation, ecological restoration, wildfire prevention, and timber stand improvement.

However, there is also the potential for increased demand to drive unsustainable levels of harvesting, with negative consequences for biodiversity, soil, and water conservation.

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Gambia policies should strive to ensure the sustainability of woody biomass harvesting; this will go a long towards winning the public trust that is so essential if bioenergy is to be become a trusted and utilized component of the national energy system.

Although sustainability should be a cornerstone of Gambia biomass policy, it is important that the laws and programs do not include highly prescriptive (or proscriptive) rules for where biomass can be harvested, for what purposes, or in what quantities. The Gambia possesses a huge diversity of forest types, representing a wide variety of ecological conditions and managed for an array of social values and objectives. A sound management prescription for one forest could be wholly inappropriate for another (even, at times, a few miles away). Instead, the policies must promote informed site-level decision making that views biomass harvesting as one tool among many for achieving holistic forest stewardship objectives.

Management plans, harvesting guidelines, conservation easements and collaborative decision making are important tools for developing creative and sustainable management directives, as well as ensuring that biomass harvesting will contribute to maximizing the full spectrum of ecological and social values that forests provide.

Despite the many benefits of woody biomass, the costs associated with harvesting, transporting, storing, and utilizing the material often exceed its value on the energy market. Some of this is due to the fact that the lower ticket price of fossil fuels does not include the negative social costs associated with climate change, and more cost-effective tools, equipment, and logistical processes are currently being developed. In the meanwhile, incentives are available that improve the economic feasibility of bioenergy projects.

These incentives are costly, and can create unintended distortions in wood fiber markets, but they will likely continue to be a part of the country energy policy for some time.

In order to get the most from limited biomass feed stocks, it is preferable that these incentives treat all biomass applications (electricity, transportation fuels, thermal energy, and biobased products) equally, in proportion to the efficiency with which they reduce greenhouse gas emissions and substitute for high-carbon petroleum products.

Government policies also have an important role to play in promoting research and furthering the science of sustainable bioenergy. R&D programs, resource assessments, and extension funding are essential to realizing the full potential of woody biomass as a renewable, low carbon energy source. Such investments will help ensure that woody biomass utilization will contribute to healthy, diverse forest ecosystems.

Removing woody biomass from forests in an efficient and economic way may be the biggest forest management challenge of the next decade. The industry needs new equipment that is designate for a products that is high- volume, low-value, and has a small average size. More research is needed to better understand how the costs of biomass removal vary across the country and across forest. Research is also needed to more fully explore the impact of biomass removals on wildlife habitat, soil nutrients, and long term soil productivity.

CHAPTER 5

5 .0 FINDING, CONCLUSION AND RECOMMENDATION.

5 .1 INTRODUCTION.

The purpose of this research was to examine issues surrounding the sustainability of biomass use in the study area, in part to ensure that biomass use is consistent with environmental quality objectives and potentially to broaden outlet markets for biomass power to include “green” or “environmentally friendly” power and fuel products. Task efforts included the development of sustainability criteria based on input from local stakeholders provided via a regional sustainability focus group.

Estimates of biomass generation and availability incorporated a variety of criteria to ensure that biomass utilization did not hurt land productivity, watershed health or forested areas that have legal, regulatory or planning restrictions on management. Forest biomass generation estimates are from projects implemented on country , tribal, regional/municipal and other lands that have undergone all necessary legal, regulatory and planning processes. Forest biomass availability estimates take into account the need to use some biomass to prevent soil disturbance on project sites. Agricultural residue supply estimates incorporate restrictions on the quantity of residue that can be removed without damaging land productivity or water quality. However, these restrictions do not include all of the potential concerns and criteria that are often included under the term of sustainability.
In October 2011, a focus group on sustainability of agricultural and forest biomass held at the Gambia helped to gauge the support of local stakeholders from a variety of different viewpoints.

The results of the focus group are included in discussion of biomass availability as possible barriers or opportunities to long-run, stable biomass supplies. In addition, the focus group results provide guidance for future activities to help build a coalition of support for biomass utilization.
The broad subjects covered include the environmental and economic consequences of using biomass from forest management and of using agricultural residue for ethanol or power generation.

The major areas of concern regarding the use of forestry residues for energy include: potential positive and negative impacts on air emissions, nutrient cycling in forest soils, economics of biomass removal and full accounting of the range of risks, costs and benefits associated with forest management. Other concerns include: ensuring that all management alternatives are considered in project planning, whether power from biomass would be considered “green,” ensuring that a long-run supply would be available and evaluating the impacts of biomass use on forest management intensity.

Air emissions
• Compare controlled emissions vs. open burning / prescribed burning.
Land management issues

• Who regulates the amount that must be left on land?
• Describe methods used to quantify overstocked land.
• Public vs. private land – where should management occur?
• What is "restoration"? "Restoration" should not be used to mean "thinning" only.

Economics of forest management

• Look at full economic impacts of biomass removal / injection of Gambia dalasis into community.
• Evaluate costs / Benefits of all options, including doing nothing or other options – removing roads, prescribed burning, etc.

Power generation issues

• How do the area's low rates of electricity influence opportunities for power production
• Would biomass power be considered green?
• Ensuring that biomass power is included in green power definition.

Sustainability of biomass supply

• Not taking trees just to supply an energy site; should be done for other reasons.
• Some participants are concerned that land managers are using catastrophic fire as scare tactics to promote forest management.
• Where does biomass come from?
• How is biomass produced?
• Is management done regardless of biomass plant being there?
• What additional demand for biomass from biomass plant is being generated?
• How much is out there, now generated year after year?
• Biomass plant may be able to influence availability if they pay for biomass.
• Gambia Department of Forestry and other landowners are not necessarily driven by profits.
• Need mix of management – some thinning, some prescribe fire, some natural fire.
• What is the sustainability of supply over 10 years?
• How many years of thinning will be done?
• What happens down the line when thinning is done?
• How much is available from non-forest resources?
• What is meant by "sustainability" by various organizations? Stakeholders need to get together to discuss and debate this term.

Concerns related to agricultural residue utilization include: difficulty of quantifying annual acreage planted and harvested in particular crops due to variability in crop practices, long-run trends in crop practices, farmer preferences related to biomass utilization, competing markets for residues and commercial readiness of new technologies.

• Difficult to quantify acres grown of each crop.
• Some crops are grown based on government payments.

• Variability of amount available is important and is influenced by the amount produced in any given year.

• Environmental constraints (soil erosion, wind erosion, soil conditioning index and organic matter) will limit the amount available for energy.
• Farmer attitudes.
• Competing markets – influenced by transportation and commercial readiness of competing technologies (e.g. proposed strawboard plant is too far away).
• Need another study to look at the potential for oil-seed crops to be grown in the area as a new crop in the region.
• New climate change study is projecting reduced rainfall in the North Bank region, Central river region and Upper river region of the Gambia. How will that affect agricultural production and irrigation in the region?
• What is the potential for new, small-scale plants to use agricultural residues?
• Emissions issues.

The implications of these results regarding biomass energy utilization are that local support for, and communication about, forest management projects should continue. Developing or using an existing local, ongoing committee to provide input on whether community concerns are being met is one way to do this.

For forest biomass, the following are vital to the community:
• clear communication by landowners and land management agencies regarding the costs and benefits of forest management and biomass utilization
• evaluation of prescribed burning
• road removal and "no action" alternatives and disseminating the results of this evaluation
• ensuring that projects are driven by watershed concerns rather than a need to supply a biomass facility.

The concerns regarding forest biomass are similar to those for forest management as a whole: whether the long-run results will meet management objectives. For agricultural biomass, soil erosion constraints limit availability of some residue for use, and annual variability in crops planted will affect the composition of the feedstock supply. Local producers are concerned with making sure that technology is available and cost-effective for residue collection and conversion.
They are also interested in newer, "on-farm" technologies that could provide value-added product opportunities for farmers.

5 .2 FINDINGS.

Here, the major categories of environmental impacts associated with biomass utilization in the study area is evaluated. The environmental benefits of using biomass resources is perhaps the most significant driving force encouraging expanded use of biomass for energy production and other associated value-added products. The fundamental environmental reasons for deploying biomass technologies are global greenhouse gas control and local or regional solid waste and water quality control. Biomass energy conversion is a beneficial alternative to landfill disposal of biomass, open burning or allowing forest fuel to accumulate and contribute to unacceptable wildfire risks.

Environmental considerations associated with biomass energy conversion fall into four main categories: (1) watershed impacts, (2) emissions from the conversion process, (3) life-cycle impacts and (4) avoided emissions. The first category addresses the benefits to watersheds from reduction of wildfire risk. The second category addresses air emissions associated with energy conversion of biomass. Under the third category, life-cycle analyses consider the net energy contribution of biomass. The fourth category is based on offsets in emissions from open burning of forestry and agricultural residues.

The linkage between watershed health and forest health is frequently overlooked in the discussions of appropriate forest management and community benefit. In particular, reducing the risk of catastrophic wildfire does not only protects lives and property; it also prevents long-term impacts on riparian area, water quality associated with increased debris and sedimentation into water bodies.

Wildfire removes vegetation and exposes mineral soils, decreasing soil's ability to absorb water. This contributes to the potential for massive soil movements and mudslides following wildfires, and it also affects soil productivity for years to come. However, wildfire prevention is only one watershed benefit that can be attributed to appropriate forest management.

Appropriate use of forest management tools including thinning, pruning, prescribed burning and employing no action in currently resilient stands helps prevent catastrophic wildfires and helps create and maintain resilient watersheds, which support communities, wildlife and recreational opportunities and improve forest aesthetics. Overly dense forest stands compete for site resources, including sun, water and soil nutrients. This does not only restricts the amount of water yield from forests to riparian areas and reservoirs, but also limits forest productivity and diversity in flora and fauna. Limiting understory vegetation growth increases soil erosion and sedimentation into water bodies, affecting water quality for wildlife and human consumption.

These environmental effects create socioeconomic issues for communities, including water availability, sustained timber production and recreational opportunities associated with streams and lakes. Forest density and fuels management in strategic areas can help reverse these negative impacts.

It is useful to compare biomass with coal because both are solid fuels that employ similar technologies. However, biomass is lower in sulfur than coal. Typical biomass contains 0.05 wt % to 0.20 wt % sulfur on a dry basis. In comparison, coal has 2 wt % to 3 wt % sulfur on a dry basis. The biomass sulfur content translates to about 0.12 to 0.50 lb SO2/MMBtu.

Because of this, burning biomass to generate power typically produces less SO2 emissions than using coal. NOx emissions should usually be lower for biomass than for coal, due to lower fuel nitrogen (N) content and due to the higher volatile fraction of biomass versus coal. However, this differences may not have much influence on the selection of the technology (i.e., coal or biomass) because the compliance costs are relatively insignificant given the small difference in NOx emissions.

Biomass power production can result in a large emissions of carbon dioxide (CO2). Sometimes biomass combustion can results in a larger emission values than for fossil fuels because of the lower combustion efficiencies. However, because the CO2 released by combustion was removed from the atmosphere in the recent past through photosynthesis and new plant growth will continue to remove CO2 from the atmosphere after biomass is harvested, it is sometimes argued that biomass is “CO2 neutral.” In practice, the picture is more complicated. Other carbon flows are involved in the picture, including CO2 emissions associated with fossil fuel used in harvesting, processing and transportation operations. Although it is certain that the net amount of CO2 emitted from a biomass power plant is less than a fossil power plant, it must be recognized that under current production practices, biomass power is not a net zero CO2 process.

Biomass combustion device emissions are estimated on a site-specific basis to determine whether a particular location is appropriate for developing a facility. In many cases, data specific to a particular wood-burning appliance are not readily available. However, the U.S. EPA provides emissions factors that can be used to estimate emissions from wood-fired boilers as part of the efforts to estimate the effects of specific combustion sources and to determine the applicability of relevant permitting programs.

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The document “Air Pollution Emission Factors, 5th Edition, Volume I for Stationary Point and Area Sources,” or AP-42 Emissions Factors, lists factors for combustion systems that uses mechanical particulate collection devices for emissions controls. Emissions factors are specified in terms of pounds of emittent per million Btu (lb/MMBtu) of fuel burned.

The large mean stem diameter species of Adansonia digitata (mean = 13.4 cm) may be attributed to scarcity of water in the study region. Ground water in the sandveld area is generally at deep levels (Obakeng and Lubczynski, 2004; Stephenson et al.; 2004). Therefore Adansonia digitata" deep root characteristic of tapping groundwater at deep levels of up to 70m (Obakeng and Lubczynski, 2004) may be contributing to its large mean stem diameter. Whereas the small mean stem diameter species such as Borasus aeithipum (mean = 9.4 cm) can be ascribed to the shallow rooting systems of the tree species which does not allow them to tap water at deep levels.

A logistic model is a member of the generalized linear model (GLM) family. Compared to other models that have continuous response variables, the response variable of a logistic model is categorical, i.e., discrete, dichotomous, or ordinary. On the other hand, the explanatory variables have no limitations on data types. Generally, the response variable is dichotomous, such as win/loss or success/failure. The response variable can take the value "1" with probability θ of success, or the value "0" with probability (1 -θ) of failure. The advantage of a logistic model is that the explanatory variables' types can be discrete, continuous, dichotomous, or mixed. Moreover, logistic regression has no limitations on the distributions of the explanatory variables. It is not necessary for the explanatory variables to be normally distributed, to be linearly related, or to have equal variance within each group. However, since the response variable is either "0" or "1" with probability of θ or 1-θ respectively, the function of an explanatory variable on the response variable is not linear. Instead, logistic regression uses a logarithm transformation to the odds 1-θ to transform the range of response result to a real number. Then the probability θ of success or of "1" is written as :

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$$\theta = \frac{e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots\beta_n x_n)}}{1 + e^{(\alpha+\beta_1 x_1+\hat{a}_2 x_2+\cdots\hat{a}_n x_n)}}$$

where
á = The constant of the equation
â = The coefficient of the predictor variables

An alternative form of the logistic regression equation is:

$$\text{Logit } [\theta (x) = \log \frac{[\theta (x)}{1- \grave{e}(x)} = \acute{a} + \hat{a}1x1 + \hat{a}2x2 + \cdots .. + \hat{a}nxn$$

The goal of logistic regression is to predict an outcome correctly using the most Parsimonious model. A parsimonious model includes only explanatory variables that are powerful in predicting the response variable. Three common methods for finding models that contain only variables that are powerful in predicting the response variable are forward selection, backward selection, and stepwise selection. In a common version of forward selection, variables enter the model one by one, where the variable added at each step is the variable that leads to the largest R-square improvement. In backward selection, all of the variables are in an initial model and then the variables are removed from the model one by one to see the improvement in a certain criteria, such as Akaike's Information Criterion (AIC) (McQuarrie and Tsai 1998). In stepwise selection, variables can both enter and exit the model. None of these three methods necessarily identifies the “best model.” Because the selection methods work by fitting an automated model to the current data set, they might not examine the combination of variables that produces the best mathematical criteria and they raise the danger of over fitting the model.

However, some criteria help protect against the danger of over fitting that emerges from the stepwise procedure. The criterion used in this thesis is the Bayesian Information Criterion (BIC), which is defined as -2Lm + mIn (n) where n is the sample size, Lm is the maximized log-likelihood of the model, and m is the number of parameters in the model.
The BIC takes into account both the statistical goodness-of-fit and the number of parameters in order to avoid over fitting the final model (McQuarrie and Tsai 1998).

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According to Larose (2005), lift charts and gain charts (cumulative lift charts) are graphical evaluative methods for assessing the predictive power

of models. Lift charts seek to compare response rates with and without the predictive model. For example, we build a model for classifying how many numbers within the whole 300 real-number data set is positive. The model classifies 100 numbers as positive, 80 of which are correct. In addition, in the raw data set 200 of 300 numbers are positive. Then a lift value for the sample size of 100 is (80/100) / (200/300) = 1.2. Lift is a function of sample size, which is why we have to specify that the lift of 1.2 for the model is measured for n = 100 records. Lift charts are plotted by putting lift values (1.2) on the y-axis and the percentage of samples drawn from the raw data set on the x-axis (In the previous case, the percentage is 200/300=0.666). When comparing different models, the larger the lift value, the better the model is. Cumulative lift charts compare models at the whole sample size level. Non-cumulative lift charts compare models at a decile level.

Classification tables are useful for summarizing the predictive power of a binary logistic regression model. The classification table cross classifies the binary outcome y with a prediction y =0 or ŷ=1 under a cutoff πo . The prediction of y is ŷ = 1 if $\delta i > \delta$ o and ŷ = 0 if $\delta i \leq \delta o$ .The two useful summaries of predictive power are sensitivity =P(ŷ =1 /y =1) and specificity = P (ŷ = 0 | y= 0).

The overall proportion of correct classifications is P(correct classification) =P(ŷ =1 and y =1) + P (ŷ=0 and y=0) = P (ŷ=1 | y =1) p (y = 1) + p (ŷ =0| y=0) p(y =0)

The overall proportion is a weighted average of sensitivity and specificity. Sensitivity provides a rate of actual positives (y = 1) that are correctly identified (ŷ= 1). Specificity measures the proportion of negatives (y = 0) which are correctly identified (ŷ= 0).

To find the best models for the two biomass-using facilities groups, this thesis uses four ways to build logistic models in SAS Enterprise Miner. The plot of these four ways is in Figure 5- 1 below. All the four ways apply the Data Partion node and evaluate stepwise logistic models using the BIC criterion. Differences among them are in the use of the Variable Selection node and the Transform Variables node. For data partition, the data set is partitioned into two parts: 60% of the data was randomly selected as the training set, and 40% of the data was randomly selected as a validation set.

The training data set was used to develop the logistic models; the validation data set was used to evaluate the performance of the logistic models. The four ways of building the logistic model are detailed as follows:
1) Data partition and stepwise variable selection for the logistic model using the BIC criterion;
2) Variable Selection node first, followed by data partition and stepwise variable selection for the logistic model using the BIC criterion;
3) All variables except Median_Family_Income are transformed into logarithm form, followed by data partition and stepwise variable selection for the logistic model using the BIC criterion

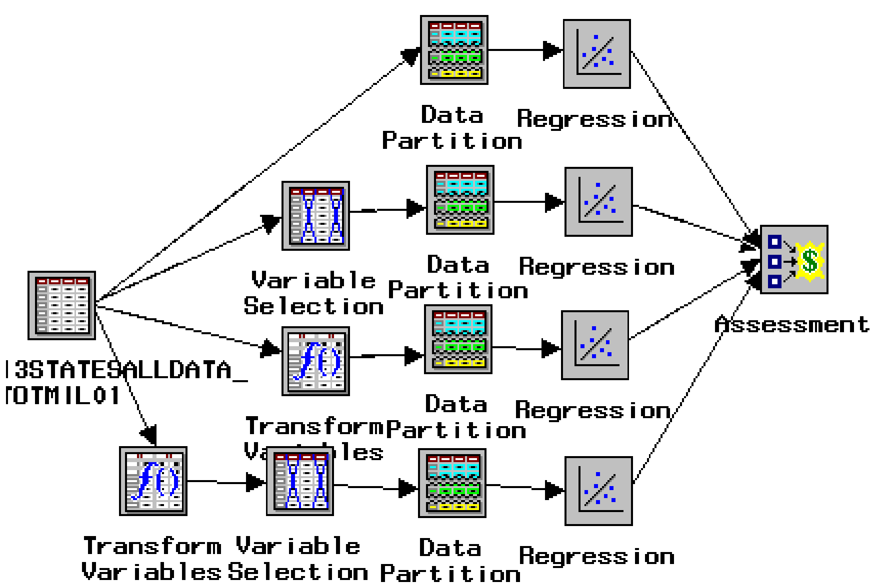

Figure 5 -1

Fire suppression and grazing in the Gambia National Forest have contributed to increased forest density and the accumulation of fuels (Kaufmann et al. 2001, Romme et al. 2003). By thinning Gambian forests to basal area targets between 40 – 60 ft2/acre, fuel loads can be reduced and the risk of crown fire can be mitigated. Harvested forest biomass can be used as fuel for energy generation with the benefit of reducing baseline emissions and earning carbon credits. Forested areas with the Highest pre-treatment basal areas will yield the greatest amount of biomass fuels and carbon credits. Fuels reduction treatments are more effective than afforestation projects in the same region for generating immediate carbon credits. Partnerships between forest managers and energy producers may partially compensate for the cost of forest fuels reduction projects and may lead to the reduction of fossil fuel emissions.

The estimates of removable forest biomass in this research are based on model projections. The specific model used was developed for the Gambia National Forest and calibrated to match actual growth conditions. Differences between modeled and actual tree growth and biomass will depend on the accuracy of the stand inventories used, climatic differences between the projected period and the period of growth that the calibration is based, and the accuracy of the model (Forest Vegetation Simulator).

Monitoring to insure that stands contain the estimated amount of biomass is simple:

• Weigh the total biomass removed (on the truck at the power plant).

• Periodically remove a sample of the biomass to measure moisture content.

Biomass Removal and Carbon - 11

• Use the moisture content, carbon content of dry biomass, and CO_2 equivalent

conversion factors to estimate CO_2 equivalent per acre.

Dry weight biomass x 50% carbon = carbon content.

Carbon content x 3.67 = CO_2 equivalent

• Measure treatment area on surveys or maps; total carbon removed/treatment area should be compared with table values.

Reuse of garbage and waste for biogas will effectively reduce methane emission while providing energy. In fact, methane contributes 10 times more than CO_2 to the green house effect.

Energy plantation can provide energy supply while effectively increased carbon sinks.
Among many renewable and alternative energy technologies, biomass energy is currently the only energy product that can substitute liquid petroleum fuel.

Biomass is the only renewable energy that human efforts can be involved in the entire process of collection, storage, transport, and energy transformation. Biomass power stations (CHP) can provide electricity for power network peak adjustment while wind power and solar PV must be provided with peak adjustment systems.

Firstly, biomass energy applications can provide employment opportunities for local farmers and increase farmers' income. Development of biomass energy will facilitate longer agriculture production chain and develop new industries in rural areas. The industry will give more income to local farmers and support more advanced agricultural sector at the same time. According to the estimate, a 25MW biomass fuel generation turbine system can produce electricity of 130 million kilowatts each year if running 6000 hours. It can be millions of Gambian dalasis value added. Over 1000 jobs can be provided for local farmers in straw collection, transportation, and processing. This would be very important for local economy in terms of solving rural labors, increasing local government income, driving local industry and service sector, improving rural economy, and upgrade Gambia's agricultural sector competitiveness at the end.

Secondly, biomass development can effectively avoid in-field fire of crop straws, livestock waste discharge, and environmental pollution by waste water and waste gas emission to the atmosphere, soil, and water bodies. While biomass resources can be non-harmed processed for energy, it can help better rural environment and higher life quality for rural residents.
Thirdly, breath system disorder is a kind of frequent disease for rural women, which is considered correlative with habit of using straw as cooking fuel in Gambia's rural areas. Biomass technologies can help provide clean energy and largely reduced the use of crop straw firing. Cleaner in-house environment would reduce the disease cases.
Currently rural area is the weakest in Gambia's social and economic development, with backward infrastructures and slow farmer income growth.

Biomass resources are mainly from agriculture and forestry. Therefore, development of biomass energy will contribute to the rural development.
In terms of energy supply, due to the lagged infrastructure development, about 7,000 rural residents still has no electricity access in Gambia that make them far from modern life style. In addition, about 70% of rural energy sources come from crop straws and fire woods, with very low energy efficiency. On the other hand, biomass resources are very abundant in the country areas. Application of the biomass resources can help electric power supply at the remote rural areas. Fully used of the local biomass energy resources will provide rural residents with clean energy and improve their life quality.

For environmental benefits, biomass development and applications will improve rural productivity and life quality, and contribute to an energy saving and environmentally friendly social development. Through making use of the previously abandoned agricultural and forestry residues for energy by collecting and processing the resources, straw and livestock waste, pollution can be effectively resolved and rural environment can be significantly improved. Meanwhile, application of the agricultural biomass will produce large amount of organic fertilizers. The abundant organic fertilizers can in turn improve soil organism and reduce usage of chemical fertilizers and pesticide.

While looking at social benefits, biomass development will promote rural industry and small township development, which will reduce gap between urban and rural life standard. Development of biomass energy will facilitate increased farmer's job opportunities and income, improved environment, reduced disease, and improved rural life quality. It will also help improved rural energy supply. With the significant environmental and social benefits, biomass energy sector development in rural area will become an effective and Practical approach for promoting the modern agriculture and rural development program through biomass industry driving force.

The non- reliability of the model stem method can be linked to a number of reasons; Firstly, the size of the grid cells could have contributed to this scenario. Time constraint was the main reason for not trying the different grid cells. However the grid cell of 3 mm tested and found to be adequate by Adhikari (2005) was used.

Other grid cells sizes tested by the same source were 2 by 2 mm and 4 by 4 mm. Adhikari (2005) concluded that the smaller the grid cell the better the results but for practical reasons, 3 mm was found to be adequate.
Secondly, as it was also observed by Montes (2000), the main limitation of this method is the requirement for a complete tree outline on the photograph. This therefore means that if the outline of the tree is not clear on the photograph then the user may introduce bias which may lead to either over-estimation or underestimation being introduced when grid cells which are supposed to be left out, are counted as falling within the tree boundary. Under-estimation would be when the grid cells which should be included in the counting are left out. The other reason can be linked to a situation where a grid cell does not entirely cover part of the tree. For this research, a condition was set that if a grid cell does not entirely cover part of the tree, it will be included or excluded in alternates i.e first time in, second time out, third time in, fourth time out etc.

Thirdly, when taking tree photographs in the field, the same distance of 5 m was maintained as far as possible for all the trees sampled. This was done to avoid discrepancies between scale calculations for the same tree which plays an important role in the ultimate biomass estimation. However, human errors in the form of variations in the distance between the tree and the camera as well as the tilt angles (either backwards or forward) of the camera could have been introduced in the field.

Lastly, since this research was focusing on woody biomass component of the tree, it was very difficult to locate the boundaries of stems and or branches covered by the leaves. Therefore an error could have been introduced leading to the method's overestimation of biomass.
Although Adhikari (2005) concluded that the model stem method appears to be a reliable method for the study of aboveground biomass of isolated trees and tree stands in open woodlands, In fact the results suggest that sub-sampling is the most reliable method (other than the model stem method) for the study of aboveground biomass of tree stands in open woodlands. The sub-sampling method was first developed and demonstrated by Valentine et al., (1984), adopted, improved and used by de Gier in several of his researches (de Gier, 1989; de Gier, 1995; de Gier, 1999; de Gier, 2003) in the Netherlands, Africa and central America .

All the researchers came to the same conclusion that the approach is efficient, provides unbiased estimates, and avoids the time consuming and laborious task of weighing the whole tree. All these are consistent with the findings of this thesis. The method worked well for the different trees species in the study area, proving its applicability and that the form of the tree species is not relevant.

One aim of this study was to evaluate the different biomass estimation method which can provide timely and cost effective source of information with limited resources for careful planning and management of the woody biomass resource. Based on the results of this thesis, time analysis revealed a very close tie between model stem and sub-sampling methods in-term of time requirement per tree in the field, and in the office. However, analysis shows an unfavourable position of sub-sampling method against model stem method.

Time required by sub-sampling method per tree.

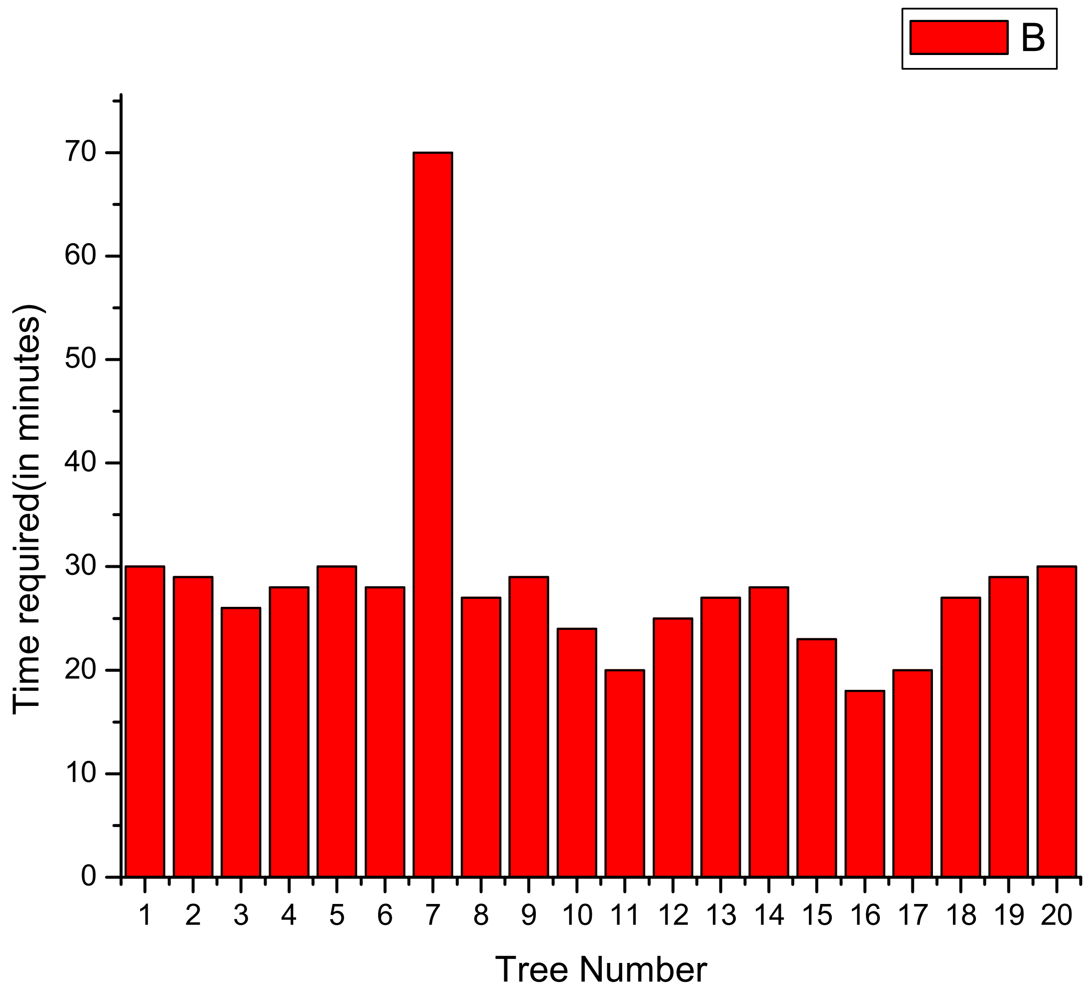

Figure 5 -2.

Model stem method.-Time required by model stem method per tree.

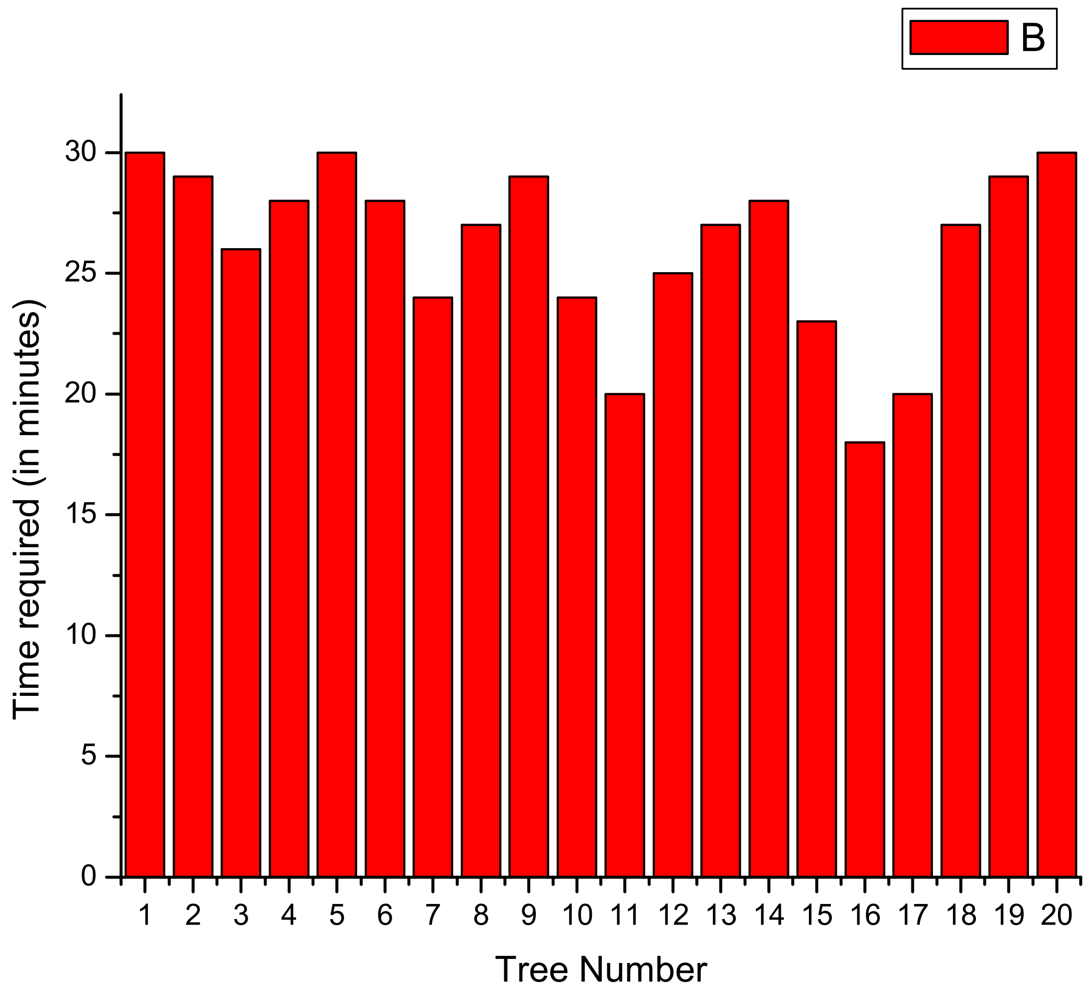

Figure 5 -3.

It requires an average of 20 minutes (ranging from 15- 30 minutes) for a single tree to be processed for biomass obtained using model stem method while an average of 25 minutes (ranging from 20- 70 minutes per tree) is required for the same process using sub-sampling method. This different which favours model stem method can be attributed to the fact that one spread sheet is designed as a calculation platform for all the trees used for the method. This improved the processing time and hence the relatively low average time per tree, hence its low cost. However, the method requires that different grid cell sizes be tried for optimal output, but due to time constraints this was not done and the grid square size of 3 mm found by Adhikari (2005) to be adequate was used. Therefore, if different grid cell sizes could have been tried, the time requirement could have been different. Unfortunately the originator, i.e. (Montes et al., 2000) and the proponent of the model stem method, i.e (Adhikari, 2005) did not include the time cost analysis in their studies therefore, it is assumed that this is the optimal time requirement for this method.

For the sub-sampling method, the findings indicate that time in the range of 10- 72 minutes averaging 25 minutes is required for processing one tree. The processing entails felling the tree, path selection, sampling and disk removal and weighing the removed disk. The results are in line with those of de Gier (1989) who implemented the method in a similar type of vegetation but in the Netherlands. The time requirement found by de Gier ranged from 10 minutes to two hours (depending on the tree size) for a crew of two with an average of 30 minutes per tree. The slightly lower time revealed by this research can be associated with the on-average smaller tree diameters characterizing the study area. Though the sub-sampling method (for one path) was 5 minutes on average slower than the model stem method, the former is still very efficient with regard to time usage cited in literature (de Gier;1989). The sub-sampling method will provide an alternative method for estimated aboveground woody biomass timeously and with high levels of reliability and low cost. The estimation of quantities of the resource would be possible hence informed and guided decision making process would be possible.

Time was also recorded for complete harvesting method and the results show that average time per tree was only 23 minutes ranging from 5-68 minutes (depending on the size of the tree).This results are not consistence with the results of many researchers (Brown, 1997; de Gier, 1989; de Gier, 2003; Stewart et al.; 1992; Vann et al.; (1992) observed that this method is prohibitively time consuming and generally impractical (Vann et al.; 1998) such that even with several workers it is often difficult to fell and weigh more than 20 trees per day. De Gier (1989) point out that heavy weighing scales are necessary requiring a lot of time for set up.

However, the results in this research are due to the fact that the trees in the study area are predominantly small, hence felling the tree and dividing it into components for taking the weight was easy and fast. A spring scale of 50 kg was used for weights measurements, hence smaller tree were not divided into components.

Sub-sampling method.

Biomass estimated through sub-sampling method against measured biomass (kg/tree).fig 5-4 below.

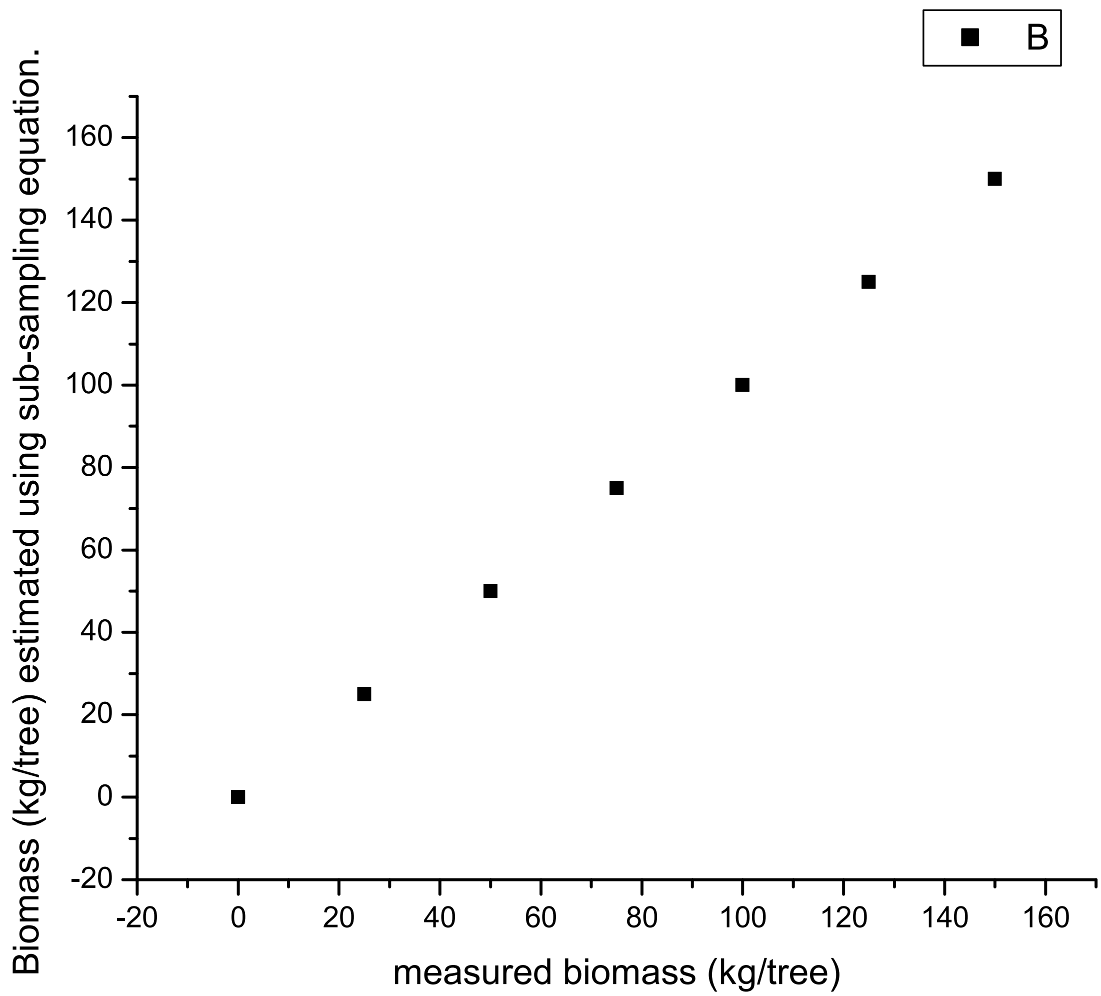

Figure 5 -4.

Rice hull is the largest category of agroindustrial residues, followed closely by [FAO, 1984, 1986]. coconut shells, cottonseed and groundnut hulls, palm and coffee residues accrue in much smaller amounts in the Gambia.
Rice hulls are a low density, low nutritive by-product of the rice-processing industry and are generally considered a nuisance [Oyenuga, 1968; F. A. Bernardo, pc]. In many countries, rice husks are consumed in the boilers of rice processing plants [WB*:* Indonesia, 1981, WB: Madagascar, 1987; Bernardo, pc]. They are also used as domestic cooking fuel [Waddle, 1985; Islam et al., 1984; WB: Thailand, 1985]

and for animal feed [WB: Madagascar, but there is also evidence that they are left in heaps to decompose [WB: Madagascar, 1987] or burned in the open [Roberts, 1973]. Estimates of how much is burned are rare. I interpreted phrases such as "substantial quantities" [WB: Thailand, 1985] and "all" [WB: Indonesia, 1981] of the rice husks produced from milling operations consumed as fuel to mean 100% rice husk used in the processing plants in southeast Asia. In India, rice processing plants are frequently diesel powered, hence, rice hulls accumulate in piles around the mill and are burnt there [R. Huke, pc].

It is estimated that 40% of rice hulls are burnt outside the mills. For Africa whose rice production is only 2% of the global total the WB reports for Mali [1991] and Madagascar [1987] suggested that rice husks are used as an energy source in the factories, that small amounts are used for fodder, but that much of the residue is hauled away to decompose or burn. It is assumed that 50% is used as industrial fuel, 45% is burned in the open field, and 5% is left to decompose.

Coconut residues are the most important of the minor agricultural residues. The largest suppliers of coconuts are Indonesia, the Philippines, Malaysia, and Sri Lanka. In many cases, the husks and shells are needed for open-fire drying of the copra [Thampan, 1987; Push parajah and Soon, 1986; WB: Western Samoa, 1985; WB: Tanzania, 1984; WB: Vanuatu, 1985; WB: Solomon Islands, 1983], for the fuel in the boilers of the processing factories [WB: Western Samoa, 1985; WB: Ivory Coast, 1985], for charcoal-making [WB: Ivory Coast, 1985; Pushparajah and Soon, 1986], and for domestic fuels [WB Benin, 1985; WB: Ivory Coast, 1985; WB: Western Samoa, 1985]. These sources provide some data on how much husk and shell may be burned. It was assumed that the use of coconut residue as boiler fuel would be 50-60%, with the remainder used for estimated open-air drying of copra. Where specific estimates are given for such use as charcoal making and fish-drying [WB: Ivory Coast, 1985], we assume these figures to be the estimates of domestic fuel use.

Cottonseed hulls are burned in processing industries, mainly in vegetable oil refineries [WB: Burkina, 1986], but also in sugar refineries [WB: Uganda, 1983] and breweries [WB: Malawi, 1982]. Some individual reports give estimates of the amount of cottonseed husks used for agroindustrial fuel, 30-75% in Togo and 100% in Ivory Coast [WB Togo, 1985; WB Ivory Coast, 1985].

It was assumed that 75% of the waste is used as industrial fuel in cotton-growing countries where quantitative information is lacking, and that the remaining 25% decomposes or burns in the fields [WB: Niger, 1984].

Groundnut hulls are often used as fuel in the groundnut processing plants [WB: Senegal, 1983; WB: Gambia, 1983; WB: Sudan, 1983; WB: Thailand; 1985]. Estimates of this use vary from none in Mali [WB: Mali, 1991] and Guinea Bissau [WB: Guinea-Bissau, 1984] to 50% [WB: Senegal, 1983] and 100% [WB: Gambia, 1983]. Remaining groundnut hulls are left to decompose or burn [WB: Mali, 1991]. It is assumed that equal amounts were used as agroindustrial fuel and burned in the open (possibly near the plants) in the countries for which we have no specific data.

.Malaysia, Indonesia, and Nigeria provide 80% of the world's palm oil. In Malaysia, leftover fruit bunches are burnt on site at the mills [Philips, pc; Husin et al., 1987; Salam, 1987]. Similarly, in Nigeria the fibre and shells are used as fuel in the steam boilers [Omereji, 1993]; shells are also used as artisanal and household fuels [Ay, 1980]. Additional detailed reports on palm oil processing in Benin [WB: Benin, 1985] and Togo [WB: Togo, 1985] suggest all residue in this industry is used for energy. It is assumed that 100% of palm processing residues are burned as part of the industry, except in Nigeria where 100% of the empty fibre bunch and 50% the shells are assumed to be burnt as part of the industry, with the other 50% used as household fuel.

To compare the amounts of biomass burned, all data were expressed in gravimetric units. Wood fuel amounts in volumetric units was converted to units of weight using conversion factors of 1.4 m3/ton (15% moisture content), or 1.5 m3/ton, depending on whether the wood was more dense (in the more arid regions) or less dense (in regions with significant rainfall) (Openshaw, pc). If survey data include a volume to weight ratio, it supersede my default values.

Openshaw [1986] provides a detailed discussion of the factors influencing the energy content of various types of biofuels. The moisture content for wood, and moisture and inorganic content (ash) for crop residues and dung are the main determinants of their energy values. As the moisture content of wood varies from wet to fully dried, the energy values range from 8.2 MJ/kg to 18.7 MJ/kg [Opens haw 1986];

or a default chosen to be 16.0 MJ/kg as the energy value for fuelwood, assuming a 15% moisture content (dry basis). For crop residue, the energy values range from 5.8 MJ/kg for fresh (100% moisture) residue with 20% ash content, to 16.7 MJ/kg for a completely dry residue with 5% ash content; for my default residue energy value was selected to be 13.5 MJ/kg, for 10% ash content and 15% moisture content (dry basis). The energy values for dung range from 6.8 MJ/kg for wet matter and 25% ash content to 17.0 MJ/kg for totally dry matter and 20% ash content; 14.5 MJ/kg was chosen as default. For conversion to amount of carbon per amount dry matter, the multiplicative factors 0.45 gm C/gm DM for wood, 0.40 gm C/gm DM for crop residue, and 0.35 gm C/gm DM for dung was used [Smith et al., 2000], unless other conversions were indicated.

The emission factors of trace gases from biomass combustion are influenced by several factors including the actual amount of carbon in the preburned dry matter, the size, shape and moisture content of the sample, and the flaming versus smoldering pattern of the burning process [Ward et al., 1996]. Most published emission factors are based on emission ratios using a carbon balance method which requires knowing the carbon content of the fuel. The carbon content of the biomass fuel is inversely proportional to the moisture content and the non-carbon ash content [Smith et al., 1993] which can range from 0.3% by weight (dry basis) for ponderosa pine to 24% for rice straw left in the field over the winter [Jenkins and Ebeling, 1985]. Carbon in the preburned biofuels or residue can vary from 35% by weight (for rice straw: Jenkins, 1993) to 54% (South Africa leaves, Susott et al., 1991), but is often assumed to be about 50% [Marufu, 1999, Smith et al.,1993]. Errors in the assumed carbon content can lead to discrepancies in emission factors calculated using the carbon balance method. This method equates the total carbon in the preburn fuel to the sum of carbon in all its postburn forms, from the charred uncombusted fuel to the volatiles [Ward and Radke, 1993; Smith et al., 1993]. Published emission factors for CO_2 are 1393 - 1620 gm pollutant/kg biofuel with carbon content ranging from 41.8 – 50 % [Smith et al., 2000; Zhang et al., 2000; Brocard et al., 1998; Smith et al., 1993; Marufu, 1999]; if a 50% carbon content is adopted, the emission factor range is reduced to 1551 – 1664 gm CO_2/kg biofuel. The distribution of carbon in the products from biomass burning: CO_2, CO, CH_4, NMHC, TSP, ash, and uncombusted fuel, is strongly influenced by the temporal pattern of flaming and smoldering (more and less efficient combustion, respectively) in the burning process [Brocard et al., 1998, Marufu, 1999, Jenkins and Turn, 1994, Ward, et al., 1999.

Several groups have designed experiments which replicate conditions commonly found in the combustion practices in developing countries in order to characterize emission factors for biofuels [Zhang et al, 1999; Brocard et al., 1998; Marufu, 1999; Bertschi et al., 2002]. Marufu and Brocard et al. used stoves common to Zimbabwe and West Africa, depression-in-the-ground and three-stone stove, respectively; Zhang et al. [1999] examined burning of 56 combinations of fuels and stoves commonly used in India and China, and Bertschi et al. [*2002*] studied traditional cooking fires in rural Zambia.

The results reported by these and other groups is displaced in Table 22. The percentage of carbon measured or assumed for the biofuel is in the first column, if available. Marufu [1999] assumed 50% carbon; He used the carbon balance to calculate the CO2 and CO emissions if he had assumed the values of Zhang et al. [2000] and Smith et al. [2000]: 45% C in fuelwood, 33.4% C in dung and 34.8% C in maize residues. Using the measured carbon content brings the results of Marufu closer to those of Zhang et al. [2000] and Smith et al. [2000], except for crop residues. In comparing emission factors it is observe that the range of factors reported from the experiments of Zhang et al. [2000] and Smith et al. [2000] encompass the factors published in the other reports, at least for fuelwood combustion. It is noted that within the developing world, domestic fuel burning involves using wood with different carbon and moisture content with different methods of flaming and smoldering, depending on the need to conserve fuel; Information on how these variables change, region to region is not available. The experiments described above use various techniques to measure the products of burning and make different assumptions of carbon dispersal. More careful assessment of traditional practices of household fuel use in the developing countries is needed, together with corresponding experiments to monitor trace gas emissions from this burning.

To derive estimates of these emissions,the following proposal were made: biofuels used in household combustion are usually air-dried (giving them higher moisture content than oven-dried samples used in experiment) and also frequently include brush and twigs with higher ash content (Jenkins, personal communication) which argues for fuel with a lower carbon content; 45% was selected For the emission factors of CH_4, NO_2, and TSP, he averaged the mean values of Smith et al. [2000] and Zhang et al. [2000], since Zhang et al. [2000] noted that these fuel/stove combinations represent a large fraction of combinations in use worldwide. The spread of values for emission factors of CH_4 and NOx is much larger than those of CO. The charcoal burning emission factors are taken from the results of Smith 2001et al. [1993] except for NOx which is from the review of Andreae and Merlet []. Two independent studies on combustion of dung [Smith et al., 2000, Marufu, 1999] give very similar emission factors for CO and CO_2, when adjusted to the correct carbon content; the values from Smith et al is chosen [2000]. For the other gases, the work of Andreae and Merlet [2001] was used. While the range of values for residue burning is large, mean emission factors for CO_2 and CO from combustion of rice straw, mustard stalk, maize residue, and wheat straw are similar.

Emissions of atmospheric gases during charcoal production depend on the type of kiln used [Openshaw, 1986, Smith et al., 1999], as well as the type and moisture content of wood used, and the skill of the operator [Foley, 1986, Openshaw, 1986]. Since emission factors are often expressed as amount of trace gas per amount of charcoal produced, and information on charcoal production is given in terms of amount of wood used for charcoal production, knowing the efficiency of the conversion process is essential to calculate the trace gas emissions. Kilns in the developing world range from the traditional earth mounds or pits with efficiencies as low as 10% [Foley, 1986] to industrial kilns with efficiencies of up to 33% [WH94].

In Africa, the earth mound kiln is used almost exclusively (Africa: Smith et al., 1999, West Africa: Brocard et al., 1998, Zambia: Hibajene et al., 1993, Malawi: Openshaw, 1997, Kenya: Kituyi et al., 1999, Pennise et al , 2001, Senegal and Tanzania: Foley and van Buren, 1982). From World Bank reports for the 1980's the estimates of efficiencies for these kilns varied from 9% to 20%, and were lower than those given in the 1990's (20-29%) [Smith et al., 1999; Brocard et al, 1998; Openshaw, 1997; Hibajene, 1993], an estimate of 15% efficiency was chosen(20% efficiency for Sudan) for our charcoal numbers for 1985, and used the emission factors of Brocard et al. [1998] as representative of all the kilns in Africa .Smith et al. [1999] described the types of charcoal kilns used in Thailand and suggested that these are representative for Asia;

the efficiencies of these kilns ranged from 29.4 to 33.3%. From other sources, estimates of 18 - 25% efficiency for kilns in Asia [WB: Vietnam, 1994; WB: Burma, 1985; IPCC Reference Manual in Smith et al., 1999], an efficiency of 25% for Asian kilns was chosen, unless specified for an individual country and used the charcoal production emission factors from Smith et al. [1999] .

Most of the charcoal used commercially in Brazil is produced in brick or mud beehive kilns which have an efficiency of 33% [WH94]. The emission factors for production in brick beehive kilns from Smith et al. [1999] was used for Brazil, as well as for the commercially produced charcoal for the steel and iron industries of Bolivia, Peru, and Paraguay. The recent report of Pennise et al. [2001] presents studies on emissions from Brazilian kilns which may provide more realistic emission factors than those chosen. For charcoal produced for domestic use in Latin America,the kiln efficiency of 17% reported in van Buren [1990] was adopted and used the IPCC (1997) default world average emission factors .

The emission factors for CO2 from residue combusted in the open field are similar to those residue used as biofuel . The open field burning emissions of CO and CH4 tend to be much lower than those measured for biofuel. Given that the moisture and ash content are very similar (Jenkins and Turn, 1994; Zhang et al., 2000), they can explain the differences by postulating that a larger proportion of uncombusted fuel remains. A variety of techniques have been used to measure emissions from burning of agricultural waste. Ezcurra et al [1996] used an aerosol dilution chamber to burn samples of cereal straw while Jenkins and Turn [1994] burned samples of barley, corn, rice, and wheat residues on a conveyor belt in a combustion wind tunnel; Nguyen et al. [1994] measured gaseous emissions during burning of rice straw out in the fields in both the wet and dry seasons, but did not provide the biomass loading.

All emission factors was presented in units of gm pollutant/kg dry matter to be burnt and compare the values for straw burning with estimates for mean values for savanna burning given by Andreae and Merlet [2001]. The residues which are the most significant contributors to field burning of agricultural waste are rice straw and barbojo. It determined emission factors for the burning gases by weighting the emissions factors for rice straw [Jenkins and Turn, 1994], barbojo, and other cereals by the fraction of global burning in fields ascribed to the three components (weighting of 40:31:20 %) my chosen emission factors fall within the ranges presented in Table 24 for CO2 and CO, are somewhat high for NOx (reflecting the dominant rice straw burning).

Decomposition of residues left in the fields after harvest is influenced by substrate composition and the environment, particularly temperature and moisture [Bell, 1974]. The tropical regions provide optimal conditions for microbial decomposition of plants. In a simple view, the sequence of the breakdown of plant matter is that the soluble organic matter (the carbohydrates in the form of starches and sugars) decompose most rapidly, followed by the proteins in the form of cellulose and hemicellulose, and finally the woody part of the stalk, known as lignin [Bel, 1974]. Since the leafy portion of the residue decomposes very quickly in the tropical rain forest [Bates, 1960] (100% decomposition),the discussion is confined to the stalks and straw of four major crops: maize, millet, sorghum, and rice.

For all four types of stalk and straw assumed that the soluble organic matter totally decomposes between the crop harvest and the next preplant burn [Martin et al., 1942; Satchell, 1974], and that the lignin portion of the residue (about 10%) remains almost entirely intact [Martin et al., 1942] and burns in the pre-plant burn. The remaining matter, the hemicellulose and cellulose portion, only partially decomposes [Swift et al., 1979]. For the case of the maize stalks, lignin represents about 8.5% of the dry weight of the stalk [Muller et al., 1971], hemicellulose about 18%, and cellulose about 30% [Swift et al., 1979].

From experiments on decomposition rates over 40% of the cellulose and hemicellulose decomposed after 30 days [Swift et al., 1979]. Using these data, it is estimated that 62% (including the soluble organic matter) of the stalks left in the fields decomposed, and that the remaining 38% is burned before planting.
The soluble cell content of millet straw is approximately 24% and that of sorghum straw about 30% [Reed, 1992; Alhassan, 1990]. Assuming that 40% of the hemicellulose and cellulose decomposes for these residues, it is estimated that 52% of millet and sorghum stalks decomposed, and 48% burn in the fields.

Quantitative information on the decomposition of rice straw was unavailable, so the estimates was based on wheat straw [Swift et al., 1979], for which about half the straw decomposes. The remaining 50% is assumed to be burned in the fields, unless other information is available.

Energy demand and consumption in The Gambia is a highly skewed affair. When expressed in tonnes of oil equivalent (TOE), fuelwood accounts for up to 84 per cent of energy consumption. Electricity and petroleum products increase this figure to 99.5 per cent, the remaining 0.5 per cent being dominated by liquefied petroleum gas (LPG) products (Njie, 2006; Saho and Ceesay, 2005). This situation obviously makes climate an important driver of changes in the energy sector.

To cushion the effects of declining natural energy products (fuelwood) resulting from continuous human pressure on forests/woodlands and decreased levels of forest productivity associated with lower rainfall since the late 1960s, households have responded by adopting one of the following measures: 1) alternative fuels (groundnut briquettes, LPG), or 2) new technology (improved cooking stoves). Big traders in fuelwood have taken to importing fuelwood from Senegal in order to maintain interrupted supplies to urban areas. A government ban on the production of charcoal products in the early 1980s was meant to slow down the rate of forest destruction, encourage uptake of new fuel-saving technology, and spur the development of private and community woodlots. It is important to highlight that a switch in energy sources is much easier for high income households, whereas middle and lower income households are more inclined towards fuel-saving technology.

Electricity supplies face seasonal threats of disruption from tree limbs detached and tossed about by violent storms. However, properly planned and timely executed tree surgery exercises appear to minimise the threat. With peak summer time demand for cooling and refrigeration routinely exceeding installed capacity, load-shedding is the power utilities favourite tool for demand management. Regarding petroleum products, it does appear that tanker delivery to Banjul port and distribution countrywide are not overly sensitive to climate variability and extremes, hence the absence of specific coping strategies.

Natural forest and woodlands (including mangroves) cover approximately 46 per cent of the country, with marked spatial differences. Amongst others, Bojang et al., (2005), and NEA (1997) report that contraction of forest area and degradation of forest quality owes more to human activities than any other causes. Nonetheless, direct and indirect impacts of climate on regeneration processes, as well as biomass productivity are nontrivial.

Tree growth parameters are affected by dry matter partitioning between wood/stems, leaves, storage organs, and roots (Spitters et al., 1989), and closely tied to climate-related factors such as soil and air temperatures, soil moisture conditions, solar radiation, etc. (Jacoby and D'arrigo, 1997). Coping with reduced productivity, stresses, and disturbances, involves the development of innovative conservation methods, and use of alternatives to forest resources. It has to be said however that not all responses are driven by conscious thought of protecting forests. In some cases urbanisation and aspirations for a modern lifestyle deserve recognition.

Whilst selective logging targets specific/marketable species, it is not clear what species are most affected by agricultural clearing. Logic points however to the rarest species in remaining mixed forest/woodland areas. Pressure on timber species such as the African copaiba balsam (Daniella oliveri), African mahogany *(*Khaya senegalensis), and African rosewood (Pterocarpus erinaues) is relieved to some extent by wood imports. Roof trusses made from fabricated metal are increasingly displacing the use of split trunks of the African Palmyra palm (Borasus aethiopium), and oil palm (Elaies guineensis). A change in food preferences in rural and urban areas alike, minimises the nutritional impact associated with the loss of important species including the baobab (Adansonia digitata), African locust bean (Parkia biglobosa), and African mango (Cordyla africana). Increasingly, people are setting up private plantations of cashew (Anacardium occidentale), mango (Mangifera indica), and Citrus spp. for commercial and other uses. One has to admit however that plantations and orchards lack the species diversity of forests, and are of questionable value for wildlife uses. Communities in the North Bank Region (NBR), which have the lowest per capita forest cover in the country, secure essential supplies of forest products through well-developed supply chains from other parts of the country.

There are apparently no specific compensatory measures to the loss of trees with known medicinal properties. Scarcity in the rural areas is addressed by wide-area searches, and/or purchase of medicinal products (bark, leaves, and roots) on local or trans-border markets. Urban areas, which are served by modern health facilities, rely less and less on medicinal plants for first aid or more chronic ailments. On the side of government, pressure on forest is reduced by setting aside forest reserves, embarking on enrichment planting and instituting a licensing system for commercial exploitation of forest resources (Bojang et al. 2005). Transfer of trusteeship to communities under social forestry programmes is a recent policy shift and practical improvement to previous forest conservation practices.

Rangelands loosely described as land not suitable for agricultural production, but incorporating fallow agricultural land and uncultivated swamps, cover an area of 500,000 hectares across the country (Bobb et al., 2005). Estimates vary by ± 10 per cent among authors (Bobb et al., 2005; NEA, 1997) due to differences in the definition of rangelands, and the dynamic changes of rangeland area. Rangeland vegetation is dominated by Andropogon spp. Fodder trees thinly populating the grasslands include in general rangelands are covered by a verdant Acacia seyal, Daniella oliveri, Ceiba pentranda, Mangifera olifera, and Pterocarpus erinaceus specimens. Oryza longistemma, Echinochloa stagnina and Vossia cuspidate are found on halomorphic soils.carpet of grass during the rainy season. Wilting and desiccation of grass cover occurs in patches and follows depletion of soil moisture reserves. Natural pressure on rangelands comes from rainfall variability and sustained periods of hot weather. A pioneering attempt to arrest and reverse impoverishment/degradation in the 1980s, within the context of the Dankunku Rangelands Management Project, fell far below expectation (Bobb et al., 2005; NEA, 1997). In retrospect, it is clear that project developers and farmers/herdsmen did not share the same objectives. However, continuous shrinkage of rangelands due to shorter fallow periods, and conversion of woodland to agricultural land, is now serving as a catalyst for closer cooperation between herdsmen and extension workers. Planting of fodder trees and start-up of intensive feed gardens are indeed some of the new approaches to increasing the biocapacity of rangelands.

These are small offshore islands, sandy shores on the Atlantic coast, and wetlands and forest biomes located approximately 20 km from the ocean. Values at risk from climate change and variability include ecological assets, real estate, fisheries and tourism sectors of the Gambian economy.

Diversion of diffuse runoff and uncontrolled storm runoff from highly urbanized catchments is responsible for sediment and nutrient loading in lowlands. An increasing trend in tidal water levels is also potentially destabilising for biota living in, and economic activities in coastal margins. Risk analysts are quick to point out that sea level rise is a creeping phenomenon with hardly noticeable effects on short time scales. However, expected damages and performance of coping strategies can be assessed from sporadic storm surges especially when these coincide with spring tides. Accelerated coastal erosion and shoreline retreat are kept within limits by a raft of measures including beach nourishment, shoreline defense (rock groynes, revetments), and regulation of sand mining operations. Regulations are also used to reduce or remove human pressure on wildlife habitats and refuges. In essence, the protected area ‘off-limits’ philosophy theoretically increases ecosystem resilience (Von Maltiz et al., 2005). Because of a significant human presence, and the absence of manipulative experiments, it is not easy to separate the effect of natural variability and human influences on the coastal environment. Suffice to say that inter-tidal communities have adequate mechanisms to cope with diurnal and intra-seasonal heat, osmotic and mechanical stresses (Tait and Dipper, 1998).

ECONOMIC ANALYSIS

The economic analysis of this research involved reviewing regional woody biomass recovery operations and examining past, current, and future regional prices for woody biomass materials. For this analysis, I gathered information from leaders in the regional forest products industry. I further obtained and analyzed information from RISI, Inc. (RISI), generally considered the leader in both the forest products and financial industries in providing economic forecasting for wood products on both national and regional levels.

Logging methods have a significant impact on the availability of forest-sourced woody biomass. Regional logging methods used for harvesting timber can be divided into two general categories: conventional harvesting and whole-tree harvesting.

Conventional harvesting means that after a tree is felled, the tree limbs and top are then removed in-place where the tree is felled. As a result, the tree limbs and tops are scattered across the entire logging area making it difficult to economically retrieve the logging slash created from conventional harvesting methods. The wood waste requires extra handling of the slash to extract it to a landing area or to pile the slash for open burning.

Whole-tree harvesting involves the felling of the tree, which is then transported to a central processing area (landing) where the tree limbs and top are removed. This type of harvesting method concentrates the logging slash in a central landing area where they can be more economically retrieved from a central location.

Historically, the majority of timber was harvested using conventional harvesting methods, which made the collection and utilization of slash created by forest residues difficult. Changing timber harvesting practices, however, have encouraged whole-tree harvesting, which significantly increases the potential availability for forest residues from logging slash created by timber harvesting.

Public and private commercial timberland owners have begun to favor whole-tree harvesting as a more efficient means of harvesting timber, especially since the removal of slash promotes the growth of seedlings and reduces open burning of forest residues. In addition, government incentive programs such as the U.S. Department of Agriculture's Biomass Crop Assistance Program (BCAP), have sought to further increase the incentive for the removal of biomass from timberlands. It is expected that central, regional, and local regulations will become more restrictive in the future with respect to open burning of forest residues, which would have the likely positive effect of increasing the supply of woody biomass for forest residues from logging operations.

An assessment of impacts on the energy sector is handicapped by a serious research deficit on the subject (Saho and Ceesay, 2005). In this context, IPCC reports (IPCC, 2001; 1996) and other studies (Njie, 2006) provide invaluable insights into potential climate change impacts. Changes in mean rainfall and temperature, as well as increased variability are expected to reduce the potential for hydroelectric power and biomass energy production.

This has ramifications, which have often been overlooked in the past. Fuelwood, a biomass energy source with low solar energy conversion efficiency (Miyamoto, 1997), currently provides 84 per cent of national energy consumption (Saho and Ceesay, 2005).

Alternative biofuels billed as solutions to petroleum energy crises however, obey the same laws of photosynthesis, which makes them equally inefficient solar energy converters. Until suitable alternatives are found therefore, The Gambia's energy dependence is bound to increase.
Subject to caveats on technological progress, higher temperature will further increase energy demand across a range of end-uses. An example that is not so evident is the increase in fuel consumption by vehicles using radiative cooling systems. Ohmic resistance of power transmission lines, known to increase with temperature, will also increase current transmission losses within power grids (Saho and Ceesay, 2005). In general, construction, protection and maintenance costs of energy delivery systems would increase in conformity with added design specifications, and facility location decisions that incorporate climate change considerations (Saho and Ceesay, 2005). It can be argued that failure to do so would increase insurance and replacement costs

Forest Resources
Similar to agricultural crops and other biomes, forest regeneration rates are expected to suffer a decline under combined effects of rising temperature and more erratic rainfall patterns. Beneficial effects of CO2 fertilization are likely to be short-lived in mature forest stands. Dry conditions and high temperatures are also noted for their contribution to forests fire hazards (Whelan, 1995). Overall effects of climate change depend on their timing and synergy. On the one hand, reduced forest productivity cuts down the amount of flammable material, thereby suppressing fire intensity. Conversely, low productivity increases susceptibility to insect attack (Sukardjo, 1994) and death. If left un-harvested, deadwood could make future fires more devastating. In freshwater parts along the estuary, lowland mangroves are likely to suffer a setback from flooding and inadequate sediment supply (Verkerk and van Rens, 2005; Sogreah et al., 1999).

Indirect negative effects may also arise from the juxtaposition of impaired ecosystem services and over-exploitation by humans and livestock (Bojang et al., 2005). Low establishment rate of new forests would precipitate further decline in the area of exploitable forest. Changes in species composition within natural vegetation cover types could arise from a combination of climatic stresses, initial composition, inter-species competition and forest use. There is already some evidence that more drought-resistant and fire-tolerant species are becoming dominant within different biomes. It is highly probable that establishment of species in new places would stem from species migration and succession rather than seed dispersal.

Health

Direct effects of climate change include stress and health complications due to thermal extremes. Although heat stress mortality may be completely new phenomenon, irrational behavioral responses such as unprotected out-door cooling could increase the incidence of malaria, dengue and yellow fever. Beneficial effects of global warming on parasite ecology, insect vector population and infectivity (Dobler and Jendritsky, 2001), could only make matters worse.

Increased flooding could put more people at risk from injury and drowning (Conteh et al., 2005). The spread of freshwater snails (Bulinus spp.) into newly flooded areas would expose a larger population to schistosomiasis. Other indirect health risks of flooding include exposure to biologically-active pollutants that may be present in flood waters. If an evacuation exercise becomes necessary, then the risk of infectious disease transmission increases with overcrowding

.Additional financial resources for health infrastructural development and disease/vector control programmes would be needed to stay within target of major health policy objectives. According to WHO (2003) cited in Conteh et al. (2005), a year-long study in Latin America indicated an 8 per cent increase in diarrhoeal admissions to a pediatrics hospital, for every degree rise in temperature.

An increase in ground-level ozone is expected to increase respiratory problems of people living, working or doing business in major business districts and along major roads (Borja-Aburto et al., 1997; Hoek et al., 1997; Sartor et al., 1995).11 A synergy between temperature, ozone and high concentrations of total suspended particulates could cause immediate health problems (aggravate cardiovascular and respiratory illnesses) for persons over 65, and long-term/permanent health effects (accelerated aging of lungs, decreased lung capacity, asthma, bronchitis, emphysema) in other age groups.

Relative risks of meningococcal meningitis outbreaks also increase with the frequency of dust storms. Although locations of future outbreaks may not be known with exactitude, urban centres with high population densities constitute the highest risky areas. Trade in and migration of domesticated animals (transhumance) or wildlife (for example birds) could be an avenue for introduction of zoonoses. Avian influenza (AI) is a typical case.

Climate Vulnerability

. In this section of the research, taking a regional approach that provides more location-specific details and therefore, better aligned to stakeholder awareness, concerns and interests. Indisputably, climate vulnerability differs according to the nature of hazard(s), degree of exposure, sensitivity and adaptive capacity of exposed units

Coastal Zone

(Banjul, Kombo St. Mary, Kombo North, Kombo South, Kombo Central, Lower Niumi)
This area is most vulnerable to sea-level rise because of its low-lying coast and heavy development in many areas (ROTG, 2003; Jallow and Barrow, 1997). Changes in seasonal rainfall patterns combined with sea level rise and global warming could also alter mangrove ecosystems significantly. Considering that 85 percent of organic carbon input to the River Gambia estuary originates from the mangrove ecosystem (Twilley, 1985),

and virtually all ichthyofauna captured in commercial/industrial and artisanal fisheries depend on mangroves for habitat, refuge from predators and food during part of their life cycle, impairment of mangrove ecosystem productivity would lead to substantial net social welfare losses.
Populations of species associated with the mangroves, including locally rare/endangered species such as the West African manatee (Trichechus senegalensis), Cape clawless otter (Aonyx capensis), brown-necked parrot (Poicephalus robustus fuscicollis) and Pel's fishing owl (Scotopelia peli), amongst others, would very likely go into sharp decline.

Disruption of migratory behaviour of birds is likely to change due to global warming (Bairlein and Winkel, 2001). Contraction and eventual disappearance of feeding and roosting areas (Njai et al., 2005) in the Bijol Islands would force migrant birds to seek out other feeding areas or risk dying from exhaustion and hunger. New nesting sites for marine turtles on sandy coastline would bring them into closer contact and conflict with humans.

People whose livelihoods are linked to the vitality of ecosystems are at significant risk of losing their livelihood. Twilley (1985) found that 51 per cent of fish caught in artisanal fisheries are involved in food webs related to mangroves. Livelihoods for hundreds of women rice and vegetable farmers working on the margins of the Tanbi wetland complex are equally threatened by rising tidal levels. Eco-tourism may be harmed by changes in the mangrove ecosystems.

Environmental changes could favour parasite ecology increasing endemicity and drug resistance. Structural changes to savanna woodland on higher ground are likely to be insignificant. In the absence of proper drainage or effective storm-water management, torrential rainfall is likely to aggravate deterioration of road stock and increase sediment and nutrient loading in lowlands.
Water supplies, already straining to meet demand, are most sensitive to seasonal rainfall distribution, global warming and heat waves. Infectious diseases could be a problem considering the high population density and mobility of the population in this area .Respiratory diseases or distress could increase from a concoction of traffic emissions and ground-level ozone.

Continental North Bank Region.
(Jokadou, Lower Baddibou, Central Baddibou, Upper Baddibou)

Dominant landscapes in this region comprise of agricultural land with trees and extensive mangroves dissected by an intricate system of channels. In some places, flood plain woodland is found on higher ground behind mangroves. The region contains most of the nation’s pristine mangrove with central Baddibou alone accounting for 60 percent of country total. Barren flats are found in the lower reaches of major freshwater tributaries of the River Gambia, Miniminium and Bao Bolon (Twilley, 1985).

Key aspects of climate change are expected to have a significant impact on lowland communities. With the exception of the Bao Bolon Wetland Reserve, backward migration of mangroves would be hampered by topographic gradients and other land uses. The character and vegetation of seasonal fresh or brackish marshes bordering the Bao Bolon is also likely to change, with lower presence of gramineae and cyperaceae species. Hemmed in by a more challenging environment, human settlements and activities, wetland communities would concentrate in the most favourable areas within the Miniminium Basin and Bao Bolon Wetland Reserve (Birdlife International, 2005).

A weaker salt flushing and inundation of wetlands would reduce productivity and diversity of brackish water species in the lower estuary. Faunal species at greatest risk from habitat modification include the Nile crocodile (Crocodylus niloticus), African rockpython (Python sebae) and royal python (Python regius).

Cultivation patterns and choice of crops may come under increasing pressure to adapt to circumstances. As a counter-measure to saline intrusion, higher investments would be required to maintain and protect rice cultivation in seasonally flooded freshwater swamps. Subject to radical management changes, open grazing may no longer be sufficient to maintain the quality of livestock products. Harvesting of timber and non timber natural products from woodland is also jeopardized by decline in productivity. It is notable that forest resources are an important or supplementary source of livelihood for the poor, and constitute the bedrock for traditional medicines.

Therefore, a significant proportion of the population could be affected by the loss of specific forest services (Bojang et al., 2005). Irrespective of its magnitude, sea level rise places some of the country's UNESCO World Heritage sites namely, James Island, Juffureh and Albreda, which are steeped in African and European colonial history, including the slave trade in this part of the world under threat from wave erosion and submergence.

Continental Western Region
(Kombo East, Foni Brefet, Foni Karenai, Foni Kansala, Foni Bondali, Foni Jarrol

This part of the country is covered by a mosaic of savannah woodland, shrubs, fallow areas and mangroves. Species composition of vegetation stands are determined by a host of natural and human factors. Natural ones include topography, tidal hydrology, soil physical and chemical properties, climate, etc.

Climate change could alter some of these factors thereby making climate one of the most important drivers of environmental change. Approximately 10 per cent of the area covered by mangroves could be flooded by sea level rise. However, loss of mangrove cover could be mitigated by migration into and succession of floodplain savannah species. A potential drop in forest productivity is also cushioned by relatively high rainfall and groundwater resources in this part of the country. However, the situation may be complicated by water use in fruit plantations and horticultural operations. Protection of rice fields in the floodplains and the viability of back swamps would increasingly depend on the presence of water control works/infrastructure.

According to Jaiteh and Saho (2006), 65 to 75 per cent of the population in this region is involved in agriculture and animal husbandry. Cattle ownership being more concentrated, pressures to bring reforms to the livestock economy are likely to create social tensions. Conflict prevention and resolution mechanisms are therefore likely to determine the persistence or otherwise of conflicts. Water-borne diseases, such as malaria, dengue fever and yellow fever may increase following the emergence of new habitat for Anopheles and Aedes spp. and non-commensurate protection measures. Fuelwood supplies for urban areas are likely to become less dependable and more costly.

Lower River Region
(Kiang West, Kiang Central, Kiang East, Jarra West, Jarra Central, Jarra East)

This part of the country has the largest patch of savannah woodland. Not surprisingly one of its administrative units, Kiang West district, has the lowest population density in the country. Jarra Central district also endowed with significant forest cover is one of three districts that are among the six least densely populated in the country (Jaiteh and Saho, 2006).

Dense mangrove belts along the River Gambia and numerous creeks in this region are expected to suffer some stress due to sea level rise, and also from reduced salt flushing arising from natural and regulated freshwater inflows (COTECO, 2006). Escarpments stretching between Mootah Point (River KM65) and Krul Point (River KM120), overlooking the River Gambia would be a formidable constraint for species migration. Slow-moving threatened species such as Rhizophora spp., and Laguncularia racemosa could disappear locally.

The resilience of savannah woodland and anomalous vegetation patterns along the Bintang Bolon (Cham et al., 2001) suggest that climate change will have little impact on vegetation. Grazing pressure from lowland migrant species is not expected to make any difference. Farming and animal husbandry which constitute a source of livelihood for more than 65 per cent of the population could be harmed by erratic rainfall patterns, contraction of shrub savannah and bush fires (Bojang et al., 2005; Cham et al., 2001).

Artisanal fishing will also suffer from mangrove losses and changes in the hydrological regime of bolons and the River Gambia. Sediment mobilised by cross-currents from submerged barren flats could compound these problems Due to high mobility and distance travelled by users of the Trans-Gambia route and national highway that meet at Soma, the risk of infectious disease outbreaks in this region, and/or outward propagation may be relatively high.

Central River Region
(Niamina Dankunku, Niamina West, Niamina East, Fulladou West, Lower Saloum, Upper Saloum, Nianija, Niani, Janjangbureh, Sami)

The River Gambia in this part of the country is characterised by meanders anabranches, and islands. The river valley which cuts into alluvial deposits is up to 2 kilometres wide in places, and flanked by mangrove that gradually morph into freshwater riverine forest and thickets. Seasonally flooded riverine forest in the Gambia River National Park is dominated by Mitragyna inermis.

On the northern side of the River Gambia, extensive swathes of original savannah woodland have been converted to agriculture and fallow land. Shrub savannah can be found on thinner soils in the Niani and Sandu districts. Agricultural land on the South bank is carved from extensive savannah woodland close to settlements. Floodplain shrub savannah vegetation is found upstream of Bansang.

In conjunction with changes in rainfall and global warming, sea level rise could alter the tidal hydrology and physical environment significantly. According to Birdlife International (2005), river islands in The Gambia are important habitats for water fowl such as the white-faced whistling duck (Dendrocygna viduata), garganey (Anas querquedula) and spur-winged goose (Plecopterus gambensis). Faunal species most at risk include those perceived as pests, and/or a threat to human safety, and/or a source of animal protein. The hippopotamus (Hippopotamus amphibius), which meet all three criteria could therefore be under serious threat of extinction.

Agricultural and horticultural production on the river islands would become Increasingly costly to protect from natural hazards and pests. Pests in particular would be drawn by successful husbandry in an otherwise devastated environment. Dry season cattle grazing and scientific research best exemplified by the River Gambia National Park Chimpanzee Rehabilitation Programmed could become casualties of contracting range. A similar challenge is faced by cattle owners and herders in other places. As much as 90 to 95 per cent of the population who are engaged in agriculture and husbandry (Jaiteh and Saho, 2006) may need to make some tough choices in keeping with expected changes in rangeland and agricultural productivity.

It is notable that attempts to bring marginal land into production runs the risk of irreversible degradation. The overall impact of bush-fire is uncertain. Fires may destroy soil organic matter (NEA, 1997) and alter species composition, but are also recognized for their positive role in releasing nutrients and controlling pest (Whelan, 1995). Direct impacts of erratic rainfall and higher temperatures include lower groundwater recharge, but this effect is likely to be overshadowed by river regulation and relatively low groundwater abstraction rates.

New and increased public investments in causeways and dykes would be needed to access, protect and/or secure rice growing areas. Further channel braiding and increased meander sinuosity is also expected with rising sea levels. A combination of higher temperatures and permanent flooding in rice-growing areas in the lowlands is expected to increase the range of snails (Bulinus spp.) hosting bilharzias.

Upper River Region
(Fulladou East, Sandou, Wuli, Kantora)

Three broad classes of vegetation cover are found in this region. Their spatial distribution is roughly determined by a combination of landscape and surface geological factors. Flood plain shrub savannah is confined to the River Gambia valley and imperfectly-drained depressions separated from the river by minor levees. On thinner soils outside the flood plains, shrub savannah is the dominant vegetation. Securidaca longipedunculata, Combretum spp, Cassia spp. are the major species in shrub savannah, whilst Avicennia africana and Mitragyna inermis co-dominate the floodplain shrub savannah.

Dominant species owe much of their preeminence to fire, and drought resistant characteristics. Large tracts of savannah woodland are found in the Fulladou East and Sandu districts where elevation is between 20 and 30 meters above current sea level.

Climate change may alter vegetation patterns and associated faunal species. In high elevation frontier areas dominated by shrub savannah, erratic rainfall and higher temperatures may constrain the survival of annual species. These are likely to be replaced by grasses and species with higher tolerance of environmental stress. Habitat loss would compound the threat to Securidaca longipedunculata, Combretum spp, Cassia spp., normally associated with shrub savannah. Medicinal plants (e.g. Cassia sieberiana, Cassia nigricans, Detarium microcarpum, Eythrophleus guieense) and valuable grazing may be lost in the transformation process.

Subject to the degree to which annual floods are downgraded by flow regulation, sea level rise may compound flooding problems in the regional capital of Basse and environs including farmland. Torrential and unseasonal rains are also likely to take a heavy toll on agricultural production. In general, inter-annual variability of crop yields is expected to increase. Extensive flooding and high temperatures make outbreaks of infectious disease more likely.

5.3 RECOMMENDATION.

From existing Government research funds, including those from the Departments of Energy, Agriculture, and Forestry, as well as the Environmental Protection Agency, provide a targeted, substantial investment in research, applied fundamentals, and innovation to address the recalcitrance of biomass, expand co products, and make advances in feedstock production. In the near-term, technology improvements derived from research activities can be incorporated into existing ethanol plants, utilizing cellulose associated with the kernel of corn and corn stover to make ethanol production more efficient, leverage investments in existing production facilities and feedstock logistics, and increase farm income. This approach offers a cost-effective and efficient transition model to expand production of ethanol from other biomass materials.

One of the most significant barriers to commercialization of biomass ethanol technology is the unproven nature of the technology in large-scale commercial facilities.

The researcher suggest that the Government of the Gambia should offer market-based incentives for commercial demonstration and technology application to support large-scale operations resulting in large production yearly of biomass-derived ethanol at a cost that is competitive with gasoline and diesel. The production incentive program should reduce but not eliminate private sector risk to capital.

With needed research and incentives to make significant production of biomass derived ethanol possible over time, the adoption of a renewable fuels standard is essential to ensure that the nation reduces its dependence on imported oil. A National Security Renewable Fuels Act would enhance economic development in rural areas, reduce our vulnerability to oil price spikes or potential supply disruptions, reduce the “energy” trade deficit, enhance environmental quality, and set a clear path to expand domestic Production of ethanol and other biofuels from a range of agricultural and non-agricultural domestic resources in all regions of the Gambia..

The researcher recommends enacting a National Security Renewable Fuels Act requiring the use of at least 3 billion gallons a year of ethanol and biodiesel by 2015. As soon as practical thereafter, the nation should move toward production of at least 2 percent of its transportation fuel from ethanol and biodiesel relying on a growing share of that production from biomass-derived ethanol. This standard, in conjunction with a significant increase in applied research and production incentives, will make the goal of reducing our dependency on imported oil a reality. It also offers the potential for the industry to provide even greater production in all regions of the nation over time.

The researcher recognizes that certain technical issues associated with ethanol use may have the potential to impact some air quality goals. The researcher believe that the goal of developing renewable Transportation fuels should not be pursued at the expense of local air quality and that reasonable policies can and should be put in place to protect against backsliding on air quality issues. To encourage the most energy-efficient production of ethanol, the researcher recommends amending the Government tax code to provide additional per gallon incentives, based on the energy efficiency of the production process and the resulting carbon emissions.

This system should be designed in a manner that does not penalize existing corn ethanol production by reducing incentives for those processes, but rather encourages innovation by rewarding the development and use of feed stocks and processes with superior lifecycle energy and emissions profiles.

It is essential to link the National Security Renewable Fuels Act to more aggressive flexible fuel vehicle policies if Gambia are to transform the transportation fuel market. The researcher strongly encourages the Gambia National Assembly to support polices that would be transition to more uniform flexible fuel vehicle standards with the aim that all new vehicles are fuel flexible — up to 85% ethanol — over a reasonable period of time.

With nearly all new vehicles designed for the exclusive use of gasoline to which limited amounts of ethanol can be added, passenger vehicles capable of operating on higher ethanol blends will be needed to encourage larger market share of biofuels.

Public sector research and development funding has the responsibility of addressing opportunities where the potential benefits to society warrant a greater investment than the prospective returns, and where the size of the risk, or the length of the time horizon before potential gains can be realized dilute incentives for firms to conduct research. This will defines the challenge before the Gambian Government with regard to significant expansion of biomass derived ethanol and the mitigation of the growing economic and national security threat that imported energy sources — oil and, in the near future, natural gas — present.

The researcher found that of the many lauded studies on expanding cellulosic (biomass) biofuels nearly all reach the same conclusions including the need to: (1) dramatically increase funding for research, applied research, and integration of technologies and processes; and (2) invite creativity through broadly defined research and demonstration objectives rather than tight prescriptions.

The researcher also made clear that increased scale and low-cost financing alone would not achieve substantial production cost reductions. Research is needed. Thus, the researcher recommends a targeted, substantial investment in research, applied fundamentals, and innovation to:

• Overcome the recalcitrance of biomass;
• Enable product diversification including fuels, animal feed protein, and chemicals; and
• Make advances in feedstock production.

Solicitations for research activities should have broadly defined technical objectives, including the above three areas, but generally not prescribe particular technologies. This will allow for a wide range of ideas to move forward and avoid government determining which technology or approach is best in an area where many combinations of technologies and processes will be needed.

Creative, unforeseen solutions put forward by proposers are essential. A theme that should be stressed in research and development efforts is the expansion of ethanol production capability to all regions of the Gambia through the use of a range of agricultural and non-agricultural biomass (e.g., corn Stover, forest products waste, grasses, municipal solid waste). Diverse feed stocks and expanded co-products will enable the industry to significantly add to their technical capabilities, as well as overall ethanol production capacity.

Further, Gambia should ensure that resources are provided to address the utilization of cellulose associated with the kernel of corn and corn Stover. This will make ethanol production more efficient, leverage investments in existing production facilities and feedstock logistics, and increase farm income. It also offers a cost-effective and efficient transition model to expand production of ethanol from other cellulosic materials.

Research alone will not achieve the longer-term goal of producing 10 percent of our transportation fuel from domestic, renewable resources. One of the most significant barriers to commercialization of Biomass ethanol technology is the unproven nature of the technology in large-scale commercial facilities and the inherent reluctance of the financial markets to risk capital.

The researcher recommends that the Gambia government should offer market-based production incentives for commercial demonstration and technology application to support large-scale operations resulting in production of biomass-derived ethanol yearly at a cost that is competitive with gasoline and diesel.

Although the use of petroleum based cooking products such as LPG and kerosene is increasing in the Gambia, biomass fuels will always remain popular. The annualized fuel costs of LPG and kerosene systems are well above the economic means of the majority of the populace, and rising costs are making them more inaccessible.

Cheaper alternatives such as fuel-wood and biomass residues still remain viable solutions for households with lower incomes. Although these fuels are not as clean burning as LPG, improvements in fuel wood stoves and innovations in residue stoves could provide efficient alternatives. The promotion of such technologies would help alleviate the burden of purchasing expensive imported fuel products and reduce the impact of fuel wood demand.

Improvements in biomass cooking must:

>Decrease cooking time
>Reduce smoke and suspended particulates in the atmosphere, providing a healthier environment within the home.
>Be designed with traditional cooking methods in mind
>Be cost effective over their life span.
>Minimize fuel consumption, and hence reduce fuel purchases
>Be aesthetically pleasing to the user and not offend others in the community
This analysis indicated that the LT-2000 and a high efficiency pellet stove are promising options for providing economical, convenient, and environmentally responsible cooking.

A significant research and development effort is required for these systems to facilitate rural development, poverty alleviation, community health, and climate change mitigation.

Biomass energy applications can provide employment opportunities for local farmers and increase farmers' income. Development of biomass energy will facilitate longer agricultural production chain and develop new industries in rural areas. Secondly, biomass development can effectively avoid in-field fire of crop straws, livestock waste discharge, and environment pollution by waste water and waste gas emission to the atmosphere, soil, and water bodies. While biomass resources can be non-harm processed for energy, it can help better rural environment and higher life quality for rural residents.

Thirdly, breath system disorder is a kind of frequent disease for rural women, which is considered correlative with habit of using straw as cooking fuel in Gambia's rural areas. Biomass technologies can help provide clean energy and largely reduce the use of crop straw firing. Cleaner in-house environment will reduce the disease cases

Currently rural area is the weakest in Gambia's social and economic development, with backward infrastructures and slow farmer income growth. Biomass resources are mainly from agriculture and forestry. Therefore, development of biomass energy will contribute to the rural development.

In terms of energy supply, due to the lagged infrastructure development, about 750,000 rural residents still has no electricity access in Gambia that make them far from modern life style. In addition, about 60% of rural energy sources will come from crop straws and fire woods, with very low energy efficiency. On the other hand, biomass resources are very abundant in the rural areas of the Gambia. Application of the biomass resources can help electric power supply at the remote rural areas. Fully use of the local biomass energy resources will provide rural residents with clean energy and improve their life quality.

For environmental benefits, biomass development and applications will improve rural productivity and life quality, and contribute to an energy saving and environmentally friendly social development.

Through making use of the previously abandoned agricultural and forestry residues for energy by collecting and processing the resources, straw and livestock waste pollution can be effectively resolved and rural environment can be significantly improved. Meanwhile, application of the agricultural biomass will produce large amount of organic fertilizers. The more organic fertilizers can in turn improve soil organism and reduce usage of chemical fertilizers and pesticide.

While looking at social benefits, biomass development will promote rural industry and small township development, which will help smaller gap between urban and rural life standard. Development of biomass energy will facilitate increased farmer's job opportunities and income, improved environment, reduced disease, and improved rural life quality.

It will also help improved rural energy supply. With the significant environmental and social benefits, biomass energy sector development in rural area will become an effective and practical approach for promoting the modern agriculture and rural development program through biomass industry driving force.

The mixed- species equations developed in this thesis are recommended where particular tree species are threatened or cutting of trees is forbidden. The biomass equation developed in this thesis can be used by the interested organization, academic institution and research purposes as well as National Environmental Agency, Department of forestry for estimating the current standing stock of the biomass resource and to determine if the woody biomass can meet the local needs. Hence, informed decision making for the effective use of the limited woody biomass resources for its sustainability can be effectively utilized. Sub-sampling method is recommended in region of Gambia where big trees are found like the North Bank region.

If remote sensing data is to be used along with field observation, then seasonality should be considered. Though different types of spectral vegetation indices were developed by past researchers for different purposes, I recommend that more research on vegetation indices that can be used to estimate woody biomass is highly needed in the future.

5.4 Conclusions.

Based on the data collected from survey respondents and obtained from other documented sources, processed wood waste supplies currently existing at various points throughout Gambia represent an immediate opportunity to further pursue wood-to-energy production at site-specific locations. There is currently at least 17,390 green tons of processed wood waste generated annually in Gambia.

Forest biomass supplies, generated by processing logging slash and non-commercial trees from commercial timber harvest, fuels reduction and range improvement activities in Gambia currently represent an important but minor component of the country's bio-energy feedstock supply. Much (900 tons per year) of the currently processed forest biomass is produced to provide feedstock for the country.

There is potential to increase the amount of processed forest biomass supply by at least 8,128 green tons of wood waste per year based on current levels of commercial timber harvest, forest fuels reduction and range improvement activities.

The wood waste by-products generated from primary and secondary wood products manufacturing in Gambia represent an important bio-energy feedstock source. A significant amount of this processed wood waste is currently used for landscape mulch and major amounts are burned or disposed of in landfills.

Urban wood waste, generated by segregating suitable wood waste from non-suitable waste of various types at municipal waste disposal locations, represents an important potential bio-energy feedstock source in Gambia. Further mechanical processing of a significant portion of this supply type would be necessary.
Tree debris that is currently chipped or ground by private or public tree care organizations and utility line maintenance companies prior to delivery to a municipal waste site could be utilized for wood-to-energy production at the present time.

The state-wide geospatial supply/demand analysis demonstrated that the greatest concentrations of wood waste supply exists in the same general areas where boiler conversion potential is highest, based on boiler age.
Overall, the greatest potential for wood-to-energy projects is in the north Bank region and upper river region of the Gambia ,based on wood waste supply amounts and the number of boilers older than 4 years.

There are also numerous potential wood-to-energy opportunities in many other rural communities, where wood waste supply exceeds 100 tons annually. Boiler conversion to utilize wood waste biomass supply may be a viable alternative in approximately half of the region of the country.

Estimating woody biomass from spectral vegetation indices obtained from satellite imagery like IKONOS have proved to be very difficult. It shows a very poor correlation between estimated woody biomass and the spectral vegetation indices (NDVI,PVI,SAVI and EVI) which indicate that these indices are not appropriate in estimating woody biomass in the study region of the Gambia.

Finally, it can be concluded that the findings of this research work will serve as a sources of information regarding the woody biomass resources like fuel-wood , through the biomass equations developed. This information can guide the decision making process thereby providing a profound background for the development of sound policies for the development of biomass- facility plant in the Gambia, and to protect and conserved the Gambia forest and its natural habitat. It would also help the policy makers to understand the rates at which different forest ecosystems changes, grow, in developing a more accurate estimates of factors contributing to changes in the atmospheric concentration of carbon dioxide and other green house gases.

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5.5 Limitation of the study.

Due to the limited time scale and limited financial resources , the scope of the research was relatively tight. However, during the course of the thesis, it became apparent that there were several additional areas that were of interest and would merit further investigation. Therefore, potential areas for future research have been suggested.

1. The amounts and locations of other sources of biomass, including agricultural by-products such as wheat straw, corn Stover (stalk, leaf, cob & husk), shells, pits, orchard pruning and orchard removals was not investigated, and should be researched to supplement wood waste feedstock supplies for certain biomass energy facilities
2. Development of technology used to convert wood waste to bio-energy products (such as cellulosic ethanol and syn-gas) was not adequately researched on but should be looked into.

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7 .0 APPENDICES

Appendix 7-1.Fine spatial resolution sensors.

Year of	Satellite	Special resol-	ution(m).
Launch	Sensor	Panchhromatic	Multispectral
1995	IRS-1C	5.8	
1997	IRS-1D	5.2	
1999	IKONOS	1	4
2000	Eros-A1	1	
2001	QuickBird	0.61	2.44
2002	SPOT HRG	2.5,5	10
2003	OrbView-3	1	4

IRS =Indian Remote sensing satellite.
SPOT =Systeme Pour I'Observatio de la Terre.
HRG =High Resolution Geometry.

Appendix 7-2 Materials used for the field survey.

Biomass estimation method	Equipment	Purpose	Quantity.
Sub-sampling	Makers. Chissel Notebook** Hand saw** I-paq** Panga** Diameter Tape/calipers. Suunto Compass** GPS (Garmin 12XL model)** Electric scale(2000g)	For labeling the branch. For smoothing the bark. For data recording as back up. For felling trees and removal of discs. For data recording. For clearing small bushes around the tree. For dbh and dah measurements. For direction incase the GPS does not work. For navigation For weighing disks	1 1 1 1 1 1 1 1 1 1
Model stem.	Digital camera Stop watch**	For taking tree photographs. For measuring duration of time required for each method.	1 1
Complete tree harvesting	Measuring tape(30m	For plot measurement and	

	length)**	tree height.	1
	Weighing spring scale(25kg).	For full tree weight.	1
	Weighing spring scale 950kg).	For full tree weights.	1
	Plastic rope(100m long)**	For demarcating the plot.	1
	Ribbon	For marking the tree.	1
	IKONOS image printout**	For locating the plots	1
	Field Vehicle (Van)**	For transportation	1

** =common to all the three methods.
Without asterisk =common to both sub-sampling and full tree harvesting methods.

People involved =Researcher =1, Botanist =1, Support staff =1.

Appendix 7-3. Processing of Landsat 7 ETM +images.

The landsat programme is the oldest civil Earth observation programme which started in 1972 with the Landsat 1 satellite (ITC,2004).In April 1999 Landsat 7 was launched carrying the Enhanced Thematic Mapper (ETM) scanner. Today only Landsat 5 and 7 are operational though Landsat 7 is currently experiencing some technical problems regarding line stripping. The applications of Landsat TM entails landcover mapping, land use mapping, soil mapping, geological mapping, sea surface temperature mapping ,etc, (ITC,2004). Landsat 7 ETM operates in the following spectral bands.

Spectral resolution of Landsat ETM.

Bands	Spectral range(μm)	Spatial resolution
1	0.45 0.52	30m
2	0.52 0.6	30m
3	0.63 0.69	30m
4	0.76 0.9	30m
5	1.55 1.75	30m
6	10.4 12.5	60m
7	2.08 2.34	30m
pan	0.5 0.9	15m

Landsat 7 ETM+ spectral radiance range.

Band	Before 1 july 2000 Low gain High gain Lmin,Lmax.Lmin,Lmax	After1 july2000 Low gain High gain Lmin, Lmax Lmin,Lma
1	-6.2 297.5 -6.2 194.3	-6.2, 293.7. -6.2, 191.6
2	-6 303.4 -6 202.4	-6.4, 300.9. -6.4, 191.5
3	-4.5 235.5 -4.5 158.6	-5, 234.4. -5, 152.9
4	-4.5 235 -4.5 157.5	-5.1, 241.1 -5.1, 157.4
5	-1 47.7 -1 31.75	-1 , 47.57. -1 , 31.06
6	0 17.04 3.2 12.65	0 , 17.04. 3.2, 12.65
7	-0.35 16.6 -0.35 10.93	-0.35 16.54 -0.35, 10.8
8	-5 244 -5 158.4	-4.7, 243.1 -4.7, 158.3

Mean solar exo-atmospheric irradiance for particular band in Landsat 7 ETM+(ESUN).

BAND	ESUN(Wm^-2µm^-1)
1	1969
2	1840
3	1551
4	1044
5	225.7
7	82.07
8	1368

Appendix 7-4 Biomass data and tree variables—summary of tree data used for regression analysis .

Plot number.	Tree name	Number of stems	Dah @10cm from ground.(cm)	Dbh @1.3m from ground(cm)	Tree height(m)	Crown diameter(avrg) m
1	Borassus aeithiopium	1	6.5	5	2.2	2.65
2	Chlorophora regia	1	3.4	3	1.5	2.25
3	pterocarpus	2	9.9	6.2	1.65	6
4	Rhizophora racamosa	1	4.8	5.5	2.5	1
5	adansonia	1	8.2	3.9	1.8	1

Plot number	Tree name.	Sub-sampling	method	Tree complete	Harvesting method	Model stem	met
		Estimated fresh weight(avrg) kg	Time taken(minutes)	Measured fresh weight kg	Time taken(minutes)		Tin tak
1	Borassus aeithiopium	2.9	18	5.2	20	8.8	28
2	Chlorophora regia	3.5	19	2.9	11	2.8	30
3	pterocarpus	13.1	28	20	24	22.6	32
4	Rhizophora racamosa	23.9	30	18	25	30.5	21
5	adansonia	11.5	21	12	27	86.5	32

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7 .5 Survey of Models for Socio-Economic Analysis of Bioenergy Systems.

1. RETScreen

The RETScreen International Renewable Energy Project Analysis Software is a renewable energy technologies project assessment tool. The software is developed by the RETScreen International Renewable Energy Decision Support Centre in Canada and is provided free-of-charge. It can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of renewable energy technologies (RETs).

The RETScreen International software is useful for both decision support and capacity building purposes. In terms of decision support, the software provides a common platform for evaluating project proposals while significantly reducing the costs (down to one-tenth the cost of conventional studies), time and errors associated with preparing preliminary feasibility studies. Regarding its capacity building benefits, the software, together with the On-line product, cost and weather databases and On-line User Manual, serves as an ideal educational and industry/market development tool. The tool is intended to be used by technical and financial personnel from electric utilities, consulting engineering firms, financial institutions, private power developers, government and development agencies and product suppliers for a variety of purposes: preliminary feasibility studies; project lender due-diligence; market studies; policy analysis; information dissemination; training; sales of products and/or services; project development and management; product development; and R&D.

RETScreen is based on Excel workbooks. There are five key worksheets provided with each technology Workbook file.

>The “Energy Model” worksheet which is used to calculate the annual energy production of the RET project being considered.

>The second is a sub-worksheet that is specific to the particular RET (e.g. “Equipment Data” worksheet).

>The “Cost Analysis” worksheet, which is used to calculate the total initial, annual and periodic project costs.

>The Greenhouse Gas Emission Reduction Analysis (“GHG Analysis”) worksheet, which is optional and is used to estimate the greenhouse gases reduced by the proposed RET project.

>The “Financial Summary” worksheet which is used to prepare the financial analysis for the RET. Numerous financial indicators are provided to help support decisions (e.g. internal rate of return, simple pay back, net present value, etc.). The results are then presented in a simple project cash flows graph for presentation to key decision-makers.

Currently, the software can be used to evaluate eight renewable energy technologies

1. Wind energy, from larger scale wind farms to smaller scale wind-diesel hybrid system applications
2. Small hydro, from larger scale small hydro developments to smaller scale mini and micro generation applications
3. Photovoltaics, from larger scale central generation plants to smaller scale distributed generation applications.

4. Solar air heating, from larger scale industrial building developments to smaller scale residential applications
5. Biomass heating, from larger scale developments for clusters of buildings to individual building applications
6. Solar water heating, from small residential systems to large scale commercial, institutional and industrial systems.
7. Passive solar heating, in low-rise residential and small commercial building applications
8. Ground-source heat pumps, for the heating and/or cooling of residential, commercial, institutional and industrial buildings

It is important to keep in mind that the RETScreen tool is a pre-feasibility analysis model and that there are limitations that it cannot overcome; for example, the tool cannot evaluate smaller scale projects where energy storage is required, the time scale for energy production is annual, rather than a more detailed time series which would consider energy production and load variation on a much shorter time scale. Therefore its output concentrates on performance and financial data.

2. BIOSEM

The BIOSEM project was started in January 1997 under the FAIR Programme. The objective was to construct a quantitative economic model capable of capturing the income and employment effects arising from the deployment of bio-energy plants in rural communities. The model is available free of charge for download from the ETSU website.

The aim of the technique is to apply a quantitative technique to bioenergy (specifically biomass-to-energy) plants to analyse and capture the socio-economic (employment and economic) impacts in the regional economy. The model uses cash flow analysis and investment techniques to determine the profitability of both fuel production and use activities.

Using a Keynesian Income Multiplier approach, the BIOSEM techniques makes predictions about the income and employment effects arising from the installation of a bio-energy plant. These are based upon the availability of the goods and services needed to service the plant, an analysis of the prevailing local economic climate, the flow of income involved with each stage of the whole bio-energy process, the labour required to service both the feedstock production and the plant, and the role of the feedstock within the agricultural sector including the impact of any possible displacement effect.

A range of biomass fuels and conversion processes can be modelled, as can the recipient markets for heat and electricity. The modelling takes place in two phases: phase 1, which is the financial assessment and phase 2, which is the socio-economic analysis.

In phase 1, investment and profit margins can be traced to determine key financial indices for both feedstock production and for the conversion plant.

In phase 2, the model captures the direct and indirect employment and income impacts, the direct displacement impacts for any agricultural activities and the induced impacts caused by the spending of wages and profits for agricultural and bioenergy plant activities.

The technique is based on five linked Excel spreadsheets, sheets A-E.

A. Sheet A is the “scene-setter” and contains all the information – regional and Plant input data – upon which all the other sheets are based.

B. Sheet B calculates the financial viability of crop production and the bioenergy Plant over a 20-year period. It provides both annual and cumulative cash flows And investment indicators i.e. net present values, and internal rates of return, which can confirm the viability of the project, thus allowing subsequent

employment and income analysis to take place.
C. Sheet C calculates all the pecuniary leakages from the regional economy.
D. Sheet D details the displacement effect of transferring one type of crop production to bioenergy production and the impact on the primary processing of the agricultural activity displaced.
E. Sheet E calculates the final direct, indirect and induced multiplier along with the income and employment gains. The basic components of the gross effect are: the direct effect, the direct displacement effect, the indirect effect, the indirect displacement effect, the induced effect and the total net impact.
The model is useful by project developers, regional economic development officers and agencies and policy makers. It should be stressed here that the technique is not designed to give a definitive answer with regard to the number of jobs created, but rather the results should be viewed as estimates of possible income and employment creation.

3 ELVIRE

The ELVIRE (Evaluation for Local Value Impacts for Renewable Energy Sources) model is an evaluation tool for development projects involving renewable energies. It has been designed by FEDARENE's working group on renewable energies within the context of the ALTENER programme, which is administered by the European Commission's Directorate General for Energy.
The model evaluates the externalities associated with renewable energy projects, by weighing up the overall impacts of a project against its initial cost. It provides answers to question like: what are the benefits of a local renewable energy project in view of the fact that energy prices are low and that conventional energies are abundant? What are the environmental benefits of such a project?
ELVIRE indicates to a public decision maker considering whether to subsidise a project, its impacts on

(a)Regional economic development

(b)Employment

©The return on public finances

(d)Sustainable development
(e)The environment helping therefore the promotion of renewable energies, as well as the implementation of information and know-how exchange networks throughout Europe.

4. SAFIRE

The SAFIRE project, supported by the Commission of the European Communities' Directorate-General for Research and Development (DG XII) under the Joule II programme, was developed by several participants, including:
>Energy for Sustainable Development Ltd (ESD, UK)

>Institut für Energiewirtschaft und Rationelle Energieanwendung (IER, Germany)
>Institute des Aménagements Régionaux et de l'Environnement (IARE, France)
>Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW, Germany)
>Fraunhofer Institut für Systemtechnik und Innovationsforschung (FISI, Germany)
>Coherence (Belgium)

SAFIRE is an engineering-economic bottom-up model for the assessment of first-order impacts of 'rational' (i.e., renewable and new non-renewable) energy technologies on a national, regional or local level against a background of different policy instruments and scenario assumptions. SAFIRE is a framework that consists of a database and a computer model that provides decision-makers with a tool to evaluate the market and impact of new energy technologies and policies. Currently, SAFIRE is being updated to take into account the calculation of baselines within the Kyoto framework.

The model includes an extensive database for 22 renewable energy technologies (RETs), eight new non-RETs and seven fuelling options for co-generation plants including fuel cells.

The calculations in the model are divided into eight stages:

1. Energy demands
2. Demand side management calculation
3. Renewable energy technical potential
4. Renewable and non-renewable energy market potential
5. District heating market potential and penetration
6. Renewable and non-centralised non-renewable market penetration
7. Centralized electricity market penetration
8. Cost benefit analysis

Seven different cost-benefit indicators are calculated by SAFIRE:

1. Pollutant emissions
2. Employment
3. Government revenues
4. Energy and import dependency

5. Value added
6. Total and local capital expenditures
7. External costs

The model has been used for a variety of applications, ranging from micro-level local planning to market assessment for companies and international agencies, from cost benefit analyses for public institutions to local, regional, national and EU policy and planning.

5. INSPIRE

The INSPIRE (Integrated Spatial Potential Initiative for Renewables in Europe) project was funded through the European Union Joule Programme, and drawing upon the expertise of several EU countries, the model has been developed into an integrated methodology for the assessment of resource availability, financial viability and environmental factors for biomass-to energy options at both regional and national levels. Whilst this was initially conceived for biomass, it has been and can be applied to other renewable energy technologies as well.

INSPIRE is a framework for linking resource mapping with the economic assessment of biomass-to energy projects. The model links different resource assessment models (developed using GIS) with various financial models, which include both project and market-driven scenarios.

The GIS models are reliant upon local agricultural data and are derived from a number of different sources (terrestrial surveys, agricultural statistics etc).

The financial models used to get potential incomes from biomass related projects are:

>RECAP. It is project-driven computer model of biomass-to-energy systems

>BIOSIM. The model converts availability to energy content and uses this to generate the resource-cost map required for linking economics with resource analysis.

>MODEST. This model uses linear programming to minimize the capital and operational costs of energy supply and demand-side management over time.

By linking the existing resource data and the financial assessments of biomass production, with the markets for the bioenergy produced in terms of electricity, CHP and heat only, the model can predict the potential resource and the possible regional income derived from the production of biomass.