POTENTIAL ECONOMIC VALUE OF CARBON SEQUESTRATION IN KAKAMEGA FOREST AND SURROUNDING FARMS.

By

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DECLARATION

DECLARATION

I hereby declare that this is my original work and has not been presented in this or any other university for the award of a degree.

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ABSTRACT

Experts generally agree that increased concentrations of greenhouse gases (GHGs) in the atmosphere will result in changes in the earth’s climate. Increased attention by policy makers to this threat of global climate change has brought with it considerable attention to the possibility of using forests as a means of sequestering and reducing emissions of carbon dioxide in the atmosphere. As globally important storehouses of carbon, forests play a critical role in influencing the Earth's climate. Reducing GHGs can be achieved by controlling and avoiding land use changes. In many parts of the world, forests are being rapidly cleared for agriculture or pasture, destructively logged, and degraded by human-set fires. When forests are degraded or cleared, their stored carbon is released back to the atmosphere during harvest and through respiration, thus these forests are net contributors of carbon to the atmosphere. Forestry is an important sector in Kenya. The long term development of the forestry sector will definitely affect the future amounts of carbon sequestration and emission of the country. The purpose of this study was to provide an understanding of the role that Kakamega forest can play in the mitigation of climate change through carbon sequestration. It evaluates potential economic value of carbon sequestration of Kakamega forest as well as the potential of the forest to participate in carbon trading. In addition, the study investigated the status of the carbon stock in the forest, based on the biomass stock. The study adopted the tobit model to estimate the determinants of the total amount carbon that can be sequestered by trees in farms. The study confirms the huge atmospheric CO_2 that can be offset by the Kakamega forest, indicating the potential of Kenya to participate in carbon trading for both its economic and environmental benefit. The results further indicate that the major determinants of the amount of carbon that can be sequestered by trees in farms are the sex of the respondent, position of the respondent in the household, source of income, tenure status of the farm, and perception on whether trees can reduce global warming. The results of the study can expedite policy decisions regarding Kenya’s participation in carbon trading through the Clean Development Mechanism (CDM) as well as providing benefits to the national forestry sector, as well as the private owners and participants in the community forestry, in terms of an overall increase in income, and achieving self-sufficiency.

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LIST OF ACRONYMS AND ABBREVIATIONS

CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon Dioxide
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
N_2O	Nitrous Oxide
UNFCCC	United Nations Framework Convention on Climate Change

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Understanding the economic value of carbon sequestered in forests is important in addressing the risk of global climate change that has presented a profound challenge to the international community. Climate change refers to the variation in the earth's global climate or in regional climates over time scales ranging from decades to millions of years. In recent usage, it may often refer only to the ongoing changes in modern climate, including the rise in average surface temperature or global warming. These changes may come from processes internal to the Earth, be driven by external forces (such as variations in sunlight intensity) or, most recently, be caused by human activities. The major cause of climate change is excessive greenhouse gases (GHGs) in the atmosphere and is predicted to increase by 75-350% by 2100 (IPCC, 2001). The GHGs include: Carbon dioxide (CO_2) from burning fossil fuels – coal, oil, and gas, CO_2 from deforestation, Methane (CH_4), and Nitrous Oxide (N_2O). Carbon dioxide is the highest emitted greenhouse gas in the world today, mostly due to fossil fuel based energy industries and deforestation (Fung, 1994).

Forest and forest products have an essential role to play in the carbon cycle mitigation process. Reducing greenhouse gas emissions can be achieved by controlling and avoiding land use changes. Deforestation in the tropics alone accounts for about 20% of total greenhouse emissions (Chomitz, 2000). The role of forestry and land use change in climate change has been controversial throughout the Kyoto Protocol international negotiation process. There are different opinions around the globe on whether forestry activities should be counted or not. A country's position depends on factors such as whether their forests are currently or prospectively a net source or sink for carbon dioxide; whether carbon (C) stock changes in forests can be measured and verified; and the relative emphasis that should be placed on reducing emissions versus increasing sequestration.

Since early 1990's governmental and non governmental organizations across the globe have been discussing strategies to mitigate atmospheric concentrations of greenhouse gases (Hedger, 1998). Several studies have found that growing trees to sequester carbon could provide relatively low-cost net emission reductions for a number of countries (Adams, et al., 1993; Bruce et al., 1996; Callaway and McCarl, 1996; Parks and Hardie, 1995; Richards et al., 1993; Stavins, 1999).

It is widely recognized that forests play an important role in the global carbon cycle by sequestering and storing carbon, enabling the switch from more energy-intensive materials such as steel to forest products, and facilitating substitution of biomass fuels for fossil fuels (Brand, 1998). It is the role of forests in climate change that has influenced participants of the Kyoto Protocol to allow countries to count carbon sequestered in forest to be counted toward a country's emissions requirements. Preliminary research indicates that carbon through forestry practices can be cost effective. For example, Dixon (1997) estimated that sequestration of carbon through silvicultural practices could cost between $2-56 per metric ton.

Kakamega Forest is the only tropical rainforest in Kenya, left over from past millennia when dense rain forest stretched from West Africa, across Central Africa and into the highland areas on the west and eastern walls of the Great Rift Valley. The forest has been a protected area of Kenya since its vital role in the eco-system was first recognized in 1933. In addition to its richness in biodiversity, it could also play an important role in mitigation of GHGs and help in fighting the impacts of global warming. Hence there is need to assess the role of the forest in carbon sequestration. Kakamega forest is located in one of the most densely populated rural areas in the world. It is estimated that areas surrounding the forest have about 600 people per km^2 (Tattersfield et al. 2001). This implies that the farms surrounding the forest also help in mitigation of climate change by sequestering some carbon if planted with trees. The farmers practice agroforestry in their farms hence sequester carbon thereby becoming a positive externality. There is need for a comparison of carbon sequestered by the forest as well as the surrounding farms.

1.2 Problem Statement

The risk of global climate change as a result of rising greenhouse gas emissions presents a profound challenge to the international community. There is increasing concern about climate change and variability, which has led to a rapidly growing body of research on impacts of warming on the economy, which may have adverse effects on agriculture.

Changes in land use of the forest ecosystem have occurred as a result of climate changes and these have been documented by various researchers (Kifcon, 994). It is therefore important to undertake the role of forests in mitigation of climate change. The establishment of the potential economic value of forests is critical for substantial and productive agriculture and therefore to food security.

Sub-Saharan Africa which includes Kenya is hard hit by climate change. This regions experience high temperatures and low (and highly variable) precipitation. Interestingly, the economies of this region are highly dependent on agriculture (Kurukulasuriya and Rosenthal, 2003). The levels and trends of forest changes have also been aggravated by the increase in human population around the forest ecosystem. Parts of the forest have been converted to agricultural activities and settlement leading to a net loss of the natural forest area. Nonetheless, the farms surrounding the forest have the potential to sequester a certain amount of carbon that is economic value. However, the amount of carbon that can be sequestered by these farms as well as the determinants of the amount sequestered are not known. The study therefore seeks to establish and compare the amount of carbon sequestered by the forest as well as the surrounding farms.

1.3 Objectives

The overall objective of the study is to assess the potential economic value of Kakamega forest and the surrounding farms in carbon sequestration as a way of mitigating climate change through reduction of carbon dioxide in the atmosphere.

Specific Objectives

Specifically, the study aims:

1. To determine the per unit amount of carbon that can be sequestered by Kakamega forest and its surrounding farms.
2. To determine potential economic value of carbon sequestration of Kakamega forest as well as the surrounding farms.
3. To identify the determinants of carbon sequestered by trees in farms.

1.4 Research Questions

1. What is the per unit amount of carbon that can be sequestered by Kakamega forest and the surrounding farms?
2. What is the potential economic value of carbon sequestration of Kakamega forest as well as that of the surrounding farms?
3. What are the determinants of carbon sequestered by trees in farms?

1.5 Justification of the study

The world's forests provide many important benefits: The population surrounding the forests depends on it for their livelihood from which they obtain a variety of products such as food, herbal medicines, wood fuel and building materials. Froests help regulate local and regional rainfall. Forests also help slow global warming by storing or sequestering carbon. Consequently, they impact global atmospheric carbon levels and, in turn, are influenced by atmospheric carbon levels and related climate change.

Understanding the role that Kakamega forest can play in the mitigation of climate change via carbon sequestration can help in the proper management of the forest with positive implications for agriculture in Kenya. But there are very few studies on the role of forests in mitigating climate change, especially in Kenya. This study will provide a crucial step in efforts aimed at assessing and understanding the role Kakamega forest will play in mitigating climate change in Kenya. The knowledge will form the basis for achieving the country's responsibility to the Kyoto Protocol in meeting the country's net emissions targets for CO_2 and other GHGs. On the other hand, the households surrounding the forest may plant trees for other purposes other than to sequester carbon. This in turn becomes a positive externality because when farmers plant trees, for example for conservation purposes, the trees also serves the purpose of sequestering carbon. The comparison between the amount of carbon sequestered by the forest and the farms may provide a better understanding of forest conservation and/or tree planting in the surrounding farms.

Due to increase pressure on forest resources, there has been destruction on biological diversity. The 1991 Survey showed the forest had lost 50 per cent of its volume and it would take about 60 years to establish complete protection of the forest and restore it to its 1965 condition (Kifcon, 1994). There is a real danger in the next decade. One approach to conserve the forest is to examine the potential economic value of the forest to sequester carbon, disseminate this knowledge and involve local communities and other stakeholders to realise this benefit.

1.6 Scope and Limitations of the study

The study was carried out in Kakamega forest which is located in Kakamega District in the Western Province of Kenya. It is part of a larger research program Biota (BIOdiversity monitoring Transect Analysis) East Africa project which is an interdisciplinary project on biodiversity research in East African rainforests. The general objective of the project is to conduct economic analyses of strategies for conserving biodiversity and forest ecosystem functions and reconciling conflicting interests of different stakeholders of Kakamega forest.

The study area was purposively selected as it is the only tropical rainforest in Kenya rich in biodiversity and also because of the recognized vital role it plays in the ecosystem. In considering the carbon content in trees, the study only focuses on mature trees and the above ground biomass trees.

Time limit variable and resources scheduled for this research could not exhaust all aspects of interest in the study site. Unavoidable errors from respondents and those arising from sampling design may have affected the precision of the results. In real world situation and experience in the economic phenomena, most variables may be interrelated in one way or another which may not be easily understood or captured.

1.7 Definition of terms

Afforestation - Planting of trees on agricultural or other non-forest land

Biomass is the total amount of live and inert organic matter above and below ground expressed in tons of dry matter per unit area.

Climate Change- Climate change refers to the variation in the earth's global climate or in regional climates over time scales ranging from decades to millions of years.

Deforestation - Permanent land use change from forests to other uses

Greenhouse gases – This include carbon dioxide, methane, nitrous oxide, and other gases that modify the heat retention capacity of the Earth's atmosphere

GtC - 1 billion metric tons of carbon, equivalent to 3.7 billion tonnes of CO_2

Intergovernmental Panel on Climate Change (IPCC): It was established in 1988 by the World Meteorological Organization and the UN Environment Program. The IPCC is responsible for providing the scientific and technical foundation for the United Nations Framework Convention on Climate Change (UNFCCC); primarily through the publication of periodic assessment reports.

Kyoto Protocol: An international agreement adopted in December 1997 in Kyoto, Japan. The Protocol sets binding emission targets for countries to reduce their carbon emissions.

Reforestation - Planting or natural regeneration of forests after harvesting, fire, or other type of forest disturbance (perturbation)

Sequestration - The removal of carbon from the atmosphere. It is the process of increasing the carbon content of a carbon reservoir other than the atmosphere. Biological approaches to sequestration include direct removal of carbon dioxide from the atmosphere through land-use change, afforestation, reforestation, and practices that enhance carbon in agriculture. Physical approaches include separation and disposal of carbon dioxide from fuel gases or from fossil fuels.

Sink - Any process, activity, or mechanism that removes greenhouse gases

Source - Any process, activity, or mechanism that emits greenhouse gases

United Nations Framework Convention on Climate Change (UNFCCC): A treaty signed at the 1992 Earth Summit in Rio de Janeiro that calls for the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

CHAPTER TWO

LITERATURE REVIEW

A growing body of literature suggests that the Earth's surface temperature this century is as warm as or warmer than any century since at least 1400 AD (Nicholls et al., 1996). By the year 2100, the average surface temperature is projected to increase by 1.4° to 5.8° while sea level is expected to rise by 9 to 88 cm (IPCC, 2001). Greenhouse gases (GHGs) such as (CO_2), methane (NH_4), nitrous oxides (N_2O) and chlorofluorocarbons (CFCs) absorb thermal radiation emitted by the earth's surface. If more GHGs are emitted into the atmosphere they absorb more heat, which, in turn, could lead to a change in the world's climate. Among the GHGs, CO_2 is the most abundant and is responsible for more than half the radiative forces associated with the greenhouse effect (Watson et al., 2000; Schimell et al., 1995).

2.1 Forests and Climate Change

Forest ecosystems play an important role in the climate change problem because they can both be sources and sinks of atmospheric CO_2. Carbon stored in the trees is most directly affected by forest management. Forests can be managed to assimilate CO_2 via photosynthesis, and store carbon in biomass and in soil (Watson et al., 2000; Brown, 1998; Brown et al., 1996). Available estimates suggest that forests may mitigate additionally from 1 to 2 GtC (1 billion metric tons of carbon) per year between 1995 and 2050 (Brown et al., 1996; Kauppi et al., 2001). Trees and plants are essential for a stable climate. They help remove carbon dioxide (a heat-trapping gas) from the air by storing it in their leaves, wood, roots and soils. But when trees and plants are destroyed, this stored carbon dioxide is released into the atmosphere, where it contributes to climate change. In fact, deforestation and land use change contributes approximately 20 to 25 percent of the carbon emissions that cause climate change. Because the trees absorb carbon dioxide as they mature, reducing deforestation provides an important ecosystem service — carbon sequestration. The benefits of this are twofold: Forests not only contribute to a solution to climate change, but also create valuable habitat that sustains and protects the area's unique plants and animals.

Great attention is focused on tropical forestry to offset carbon emission due to its cost-effectiveness, high potential rates of carbon uptake, and associated environmental and social benefits (Brown et al., 2000; Moura-Costa, 1996; Myers 1996). Tropical forests have the biggest long-term potential to sequester atmospheric carbon by protecting forested lands, reforestation, slowing down deforestation, and agroforestry (Brown et al., 1996). However, at present, tropical forests are estimated to be a net source of 1.8 GtC per year primarily because of deforestation, harvesting and forest degradation (Watson et al., 2000). Kakamega Forest is the only tropical rainforest in Kenya, left over from past millennia when dense rain forest stretched from West Africa, across Central Africa and into the highland areas on the west and eastern walls of the Great Rift Valley.

Understanding how forest sequestration integrates with other climate change options is challenging. For the most part, climate policy is assessed with national or global economic models that capture important economic linkages in the world economy (Manne and Richels, 2001; Nordhaus and Boyer, 2000; IPCC, 2000). Methods for integrating energy models and forestry models have been used in several studies. A recent example by Sohngen and Mendelsohn (2003) linked a dynamic timber model to the DICE model (Nordhaus and Boyer, 2000), and showed that forests could account for approximately a third of total abatement over the next century. That study, however, looked at only two potential policy responses. More stringent policy targets, or policies that include additional abatement options, such as methane abatement, could lead to different greenhouse gas price paths, and different implications for the "where" and "when" of accomplishing carbon sequestration in forests.

Believed to be the easternmost relic of the Guineo-Congolian rainforest belt that once spanned the breadth of Africa (Kendall, 1969; Kokwaro, 1988; Wass, 1995), the Kakamega National Forest is Kenya's only remaining rainforest fragment larger than a few hundred hectares. Bio-physical conditions and historical accounts indicate that much of western Kenya was once forested and could still support closed canopy forest (Kendall, 1969; Kokwaro, 1988; Lovett and Wasser, 1993), however Kakamega Forest is now set in a landscape dominated by small scale agriculture and high population densities of 10 people/ha (Kendall, 1969; Kokwaro, 1988; Wass, 1995). Regional trends of forest loss have continued even within the national forest boundaries: more than 50% of Kakamega's indigenous forest cover was cleared in a span of 30 years (Wass, 1995). Despite its reduced size, the remaining 140 km2 of indigenous forest is the headwaters for the district's rivers (Kokwaro, 1988), retains a globally significant level of biodiversity (Wass, 1995), and provides essential goods and services (fuelwood charcoal, water, grazing areas, medicinal, and edible plants) to a heavily reliant local population (Kokwaro, 1988; Emerton, 1994; Wass, 1995).

2.2 The Kyoto Protocol and Climate Change

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC, 1997) establishes the principle that carbon sequestration can be used by participating nations to help meet their respective net emission reduction targets for carbon dioxide and other greenhouse gases. After fossil-fuel combustion, deforestation is the second largest source of carbon dioxide emissions to the atmosphere. Estimates of annual global emissions from deforestation range from 0.6 to 2.8 billion tons, compared with slightly less than 6.0 billion tons annually from fossil-fuel combustion, cement manufacturing, and natural gas flaring, combined (Bruce et. al., 1996 & Houghton, 1991). There are three pathways along which carbon sequestration is of relevance for atmospheric concentrations of carbon dioxide: carbon storage in biological ecosystems, carbon storage in durable wood products, and substitution of biomass fuels for fossil fuels (Richards and Stocks, 1995).

The Protocol attempted to reconcile the diversity of viewpoints on land use change and forestry. According to article 3.3 of the Protocol, land-use change and forestry activities that can be counted toward the emissions reduction target include afforestation, reforestation, and deforestation. A variety of ways in which emissions can be abated, include the Clean Development Mechanism (CDM) (IPCC, 2000). In the CDM, emission reduction projects implemented in developing countries sell certificates of emissions reductions to parties with emission reduction targets within the Kyoto Protocol. Additionally, the CDM promotes synergism, both in the energy sector and the forestry sector, such as combined energy production or fuel switching, industrial applications and land-use change, including tree plantations and forest regeneration.

The emergence of a global market for carbon credits, earned through investments in activities that quantifiably offset or reduce carbon emissions, offers a powerful, but not yet fully refined, tool to finance improved forest management and sustainable development. By 2000, well before the 2005 ratification of the Kyoto Protocol and its Clean Development Mechanism, over 150 bilateral carbon-trading projects had been developed (Bass et al., 2000), yet few have been in Africa. Model-based assessments of carbon storage in Africa's forests indicate that much of the areas that are biophysically capable of supporting carbon rich tropical forests are currently degraded and deforested (Brown and Gaston, 1995; Zhang and Justice, 2001) and that Kenya specifically could almost double its current aboveground biomass. Kenya lost 930 km^2 of closed forest from 1990 to 2000 (FAO, 2003). The Kakamega National Forest of western Kenya – a protected area with a long history of deforestation, a high use value for surrounding residents, and a constant threat of further degradation – provides a promising and important site for initiating carbon offset activities in Kenya.

2.3 Climate Change Mitigation Options

Most forest sector actions that promote carbon conservation and sequestration make good social, economic, and ecological sense even in the absence of climate change considerations. Major objectives for managing forests generally include sustainable forest development, industrial wood and fuel production, traditional forest uses, protection of natural resources, recreation, rehabilitation of damaged lands, and the like. The carbon conserved and sequestered from managing for these objectives will be an added benefit. For example, although the establishment of plantations on non-forested land provide for economic development, provide new wood resources, replace diminishing or less productive natural forests, generate wood exports, substitute for imports, or rehabilitate degraded lands (Evans, 1990; Kanowski et al., 1992), they are also an important means for sequestering carbon.

Forest management practices that meet the objectives given above can be grouped into three categories based on how they are viewed to curb the rate of increase in atmospheric $CO_{2.}$ These categories are: (1) management for carbon emission avoidance or conservation, (2) management for carbon storage or sequestration, and (3) management for carbon substitution (Brown et al., 1996).

2.3.1 Emission avoidance: The main goal of management for carbon emission avoidance is to conserve existing carbon pools in forest vegetation and soil through options such as controlling deforestation or logging, protecting forest in reserves, changing harvesting regimes (reduced impact logging), and controlling other anthropogenic disturbances such as fire and pest outbreaks. Reducing tropical deforestation and forest degradation rates would require action to reduce the pressures for land and commodities while increasing the protection of remaining forests for the purposes of conservation and timber production. Global action to mitigate carbon emissions by conserving carbon pools may lead to more interest and success in controlling deforestation and making agriculture more sustainable.

2.3.2 Sequestration: Management for carbon sequestration means increasing the amount of carbon stored in vegetation (living above and below ground biomass), dead organic matter and soil (litter, dead wood, and mineral soil), and durable wood products. Increasing the carbon pool in existing forests can be accomplished by silvicultural treatments, protecting secondary forests and other degraded forests whose biomass and soil carbon densities are less than their maximum value and allowing them to sequester carbon by natural or artificial regeneration, and to establish plantations on non-forested lands or increase the tree cover on agricultural or pasture lands (agroforestry) for environmental protection and local needs (Lugo et al,. 1993; Allen et al., 1995). There is need to asses the total amount of carbon that can be can be conserved in trees planted in farms.

2.3.3 Substitution: Management for carbon substitution aims at increasing the transfer of forest biomass carbon into products (e.g., construction materials and biofuels) rather than using fossil-fuel-based energy and products and cement-based products. Substitution management has the greatest mitigation potential in the long term (Marland and Marland, 1992). It views forests as renewable resources and focuses on the transfer of biomass carbon into products that substitute for, or lessen the use of, fossil fuels rather than on increasing the carbon pool itself. Fossil fuel substitution with biomass derived from sustainably managed renewable resources such as forests, will:

i) delay the release of carbon from fossil fuel until it is needed sometime in the future;

ii) increase standing stock of forests; and

iii) maintain their carbon sink

2.4 Theoretical Framework

2.4.1 Regression Analysis of biomass estimation method

The biomass estimation method used in the study is based on linear regression analysis approach. The linear regression equation approach requires the selection of the regression equation that is best adapted to the conditions in the study area. Linear regression models have been fitted to data in various situations of variable site and ecological conditions globally. The work done by Brown, Gillespie and Lugo (1989) and FAO (1997) on estimation of biomass of tropical forests using regression equations of biomass as a function of diameter at breast height is central to the use of this approach. Some of the equations reported by Brown, Gillespie and Lugo (1989) have become standard practice because of their wide applicability. Table 2.1 presents a summary of the equations, as found in the specialized literature, including the restrictions placed on each method. Kakamega forest and its surrounding farms has trees with diameter at breast height being greater than 5cm and having average rainfall ranging from between 1500 and 4000mm, is best suited to the biomass estimation method that was advanced by Brown et al., (1989), hence its applicability in this study.

Table 2.1 - Estimation of biomass of tropical forests using regression equations of biomass as a function of Diameter at breast height (DBH)

AUTHOR	EQUATION	Restrictions: DBH and climate based on annual rainfall
FAO	(FAO-1) Y = exp{-1.996 + 2.32 × ln(DBH)} $R^2 = 0.89$	5 < DBH < 40 cm Dry transition to moist (rainfall > 900 mm)
FAO	(FAO-2) Y = 10 ^ (- 0.535 + log10 (p × r^2)) $R^2 = 0.94$	3 < DBH < 30 cm Dry (rainfall < 900 mm)
FAO	(FAO-3) Y = exp{-2.134 + 2.530 × ln (DBH)} $R^2 = 0.97$	DBH < 80 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown, Gillespie and Lugo, 1989)	(Winrock-1) Y = 34.4703 - 8.0671 DBH + 0.6589 DBH^2 $R^2 = 0.67$	DBH < 5 cm Dry (rainfall < 1 500 mm)
Winrock (from Brown, Gillespie and Lugo, 1989)	(Winrock-DH) Y = exp{-3.1141 + 0.9719 × ln[(DBH^2)H]} $R^2 = 0.97$	DBH < 5 cm Moist (1 500 < rainfall < 4 000 mm)
Winrock (from Brown Gillespie and Lugo, 1989)	(Winrock-DHS) Y = exp{-2.4090+ 0.9522 × ln[(DBH^2)HS]} $R^2 = 0.99$	DBH > 5 cm Moist (1 500 < rainfall < 4 000 mm)

Note: p = 3.1415927; r = radius (cm); DBH = diameter at breast height (cm); H = height (m); BA = J × r^2; and S = wood density (0.61).

2.4.2 The Tobit Model

A tobit model is an econometric model in which the dependent variable is censored; in the original model of Tobin (1958), for example, the dependent variable was expenditures on durables, and the censoring occurs because values below zero are not observed.

The tobit model is also called the censored regression model or the limited dependent variable regression model because of the restriction put on the values taken by the regressand. It is used in a censored sample in which information on the regressand is available only for some observations.

Statistically, it is expressed as follows, where the relationship between the observed outcome variable, Y*i* , and the latent outcome variable of interest is:

Yi = 1 if y**i*>*0*

0 Otherwise

Where,

$y*_i = \beta_0 + \beta_1 X_i + \varepsilon_i$

The regression model to be estimated is then expressed as follows:

$Y_i = \beta_0 + \beta_1 X_i + ...\beta_j X_j + \varepsilon_i$ if RHS>0

Where $X_i \ldots X_j$ represents a set of independent variables; β_0 is the constant term, $\beta_{1\ldots}$ β_j are the vector coefficients to be estimated and ε_i is the error term being independent and normally distributed, $\varepsilon_i \sim N(0, \sigma^2)$. The unobservable variable $y*_i$ (also known as a latent variable) is related to the total amount of carbon that can be sequestered by farm *i*. We assume that the unobservable variable $y*_i$ is normally distributed with the same mean μ and variance σ^2.

The tobit model estimates the parameters by regressing Y_i on X_i for all observations, with the censored data included as zeros. It uses all of the information obtained, including information about censoring, and provides consistent estimates of the parameters.

Since all we know for censored cases is that $y^*_i \leq 0$, we use the probability of being censored as the likelihood.

In the study, it is assumed that there might be some farms which do not have mature trees hence have no capacity to sequester carbon. This necessitates the use of the tobit model so as to cater for the unobserved variables.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter presents a description of the methods employed in this study and the study area. It further presents the methods employed in sampling, data collection and analytical methods used as well as a description of the study area.

3.1 Study Area

Kakamega Forest is situated mainly in Kakamega District in the Western Province of Kenya, between latitudes of $0^o.10^1$ and 0^o 21^1N and longitudes 34.47^1 and 34^0 58^0E. Its altitude varies between 1520m and 1680m above sea level. It is a mid-altitudinal tropical rainforest and considered to be the eastern most remnant tropical rainforest of the Guinea-Congolean type (Kokwaro, 1988). Thus, it is the only remnant in Kenya of rain forest dwelling animals and plants, but due to its elevation it also contains montane elements of flora and fauna (Althof et al., 2003). It is located amidst the densest populated agricultural centre in the world with about 600 people per km^2 (Tattersfield et al., 2001) and with a population growth rate in 1990 of 3.8% (Rodgers, 1992), an increase of population density in the next decades is most likely (Cincotta et al., 2000).

Annual rainfall in Kakamega Forest ranges from 2147mm per year (as averaged from FD records at Isecheno Forest Station from 1982 to 2001) and highly seasonal with a rainy season from April to November and a short dry season from December to March. The average monthly Temperatures are between 11.4˚C-25˚C per year. (Tsingalia 1990).

The main forest block gazetted in 1933 for forest and game reserves occupies approximately 23,777 ha (Kokwaro, 1988). Kakamega forest ecosystem is an important catchment traversed by two major rivers each having numerous tributaries. The Isiuku River, which rises from the Nandi escarpment, drains the northern section of the forest while Yala River whose source is situated in Tinderet and Southern Nandi forests drains the southern section of the forest. The main agents of forest degradation have been mostly logging and extraction of commercially valuable timber, followed by charcoal burning, cattle grazing, shamba system farming, hunting for bush-meat, tree debarking and removal of dead trees for firewood (Oyugi, 1996; Mitchell, 2004). In the early 1980s a presidential decree banned all indigenous tree species exploitation, leading to a halt of commercial logging, however, tree poaching and other illegal activities still exist.

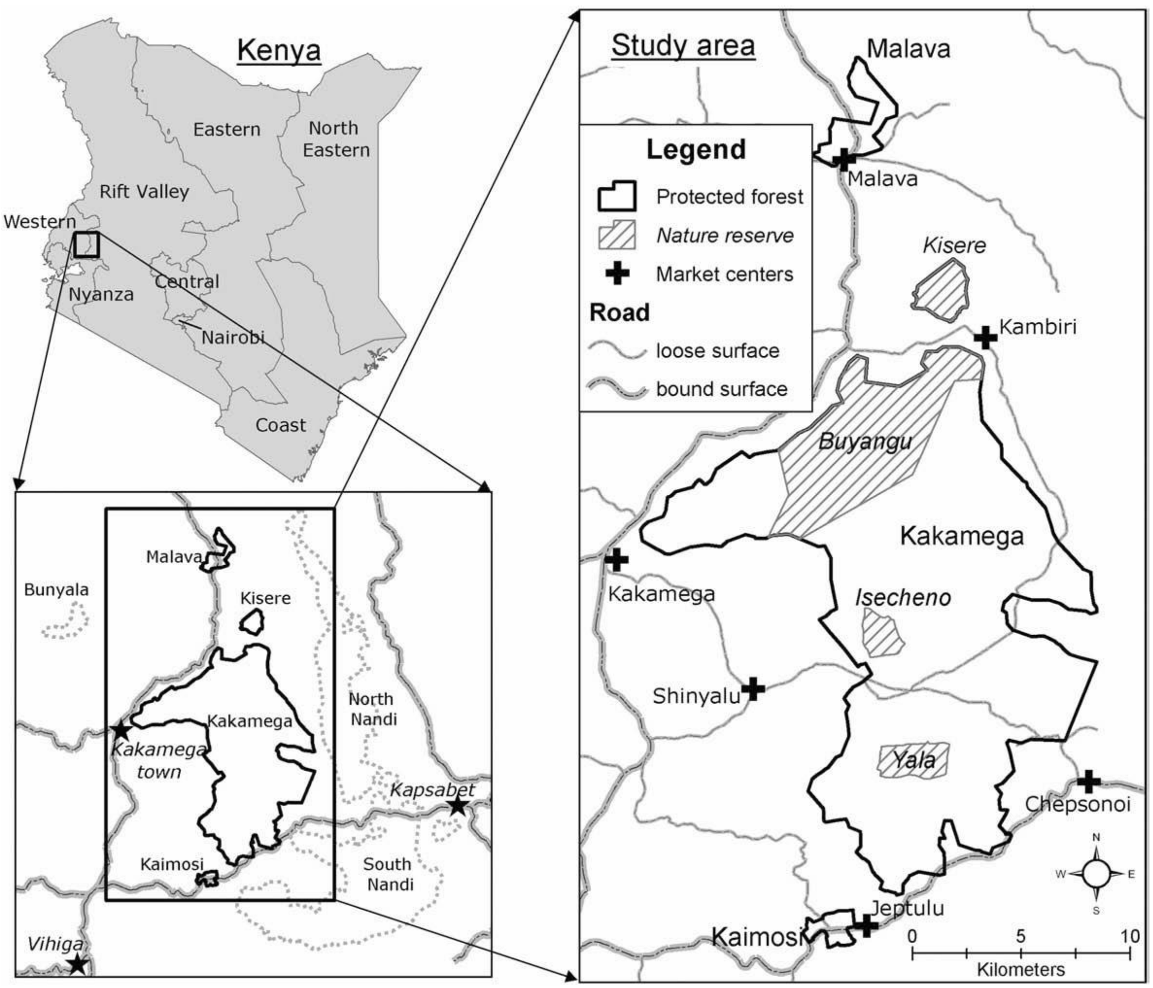

Figure 3.0: Location of the study area and the different forests covered by remote sensing analyses in western Kenya (34°37'5" – 35°9'25" east of Gr., 0°32'24" north – 0°2'52" south of the equator)

3.2 Sampling

To determine the carbon sequestration potential of Kakamega forest, information on biomass density was obtained from secondary sources from sub-projects of BIOTA East Africa. These data was used to achieve the first objective of the study. Primary data was used from the farms surrounding the forest. The sampling unit for this study is the farms surrounding Kakamega forest.

The study was undertaken within approximately 10 Km radius around the Kakamega Forest. A reconnaissance survey in the study area indicated that there are progressively fewer people that extract beyond 5km stretch from the forest (Mburu and Guthiga, 2006). The sampling frame (the list of households) of 34,000 household used was generated with the help of administrative heads of the villages and other local leaders. Given its large household population (34,000), drawing a representative sample there from will be inevitable. A representative sample size of 120 households was randomly selected stratified random sampling. The strata were the administrative zones. Each zonal sample was proportional to its population and was drawn using simple random probability sampling technique to give each sampling unit the same chance of being sampled. The formula for determining a sample from a large population was used to select a sample of 120 households. However, for a large population as is the case in this study, statistically, it is advisable that we can reliably assume that the proportion of the population containing the estimate is 50 per cent. For such a large population again we set the confidence interval at 5 percent and set the confidence level at 95 per cent (Nachmias and Nachmias, 2002). Getting a targeted sample size from such a large population entails the use of a statistical formula;

$$N = \frac{PQ}{(SE)^2}$$

where N = sample size

P = proportion of the population containing the major attribute

Q = $1 - p$

SE = standard error of the proportion

A household in this study is defined as a farm family. It is composed of all the individuals or family in a farm. Structured questionnaires were administered to the sampled farms by trained enumerators. The questionnaires elicited information on household socio-economic, farms, and demographic characteristics.

3.3 Estimation of Carbon Sequestered

Biomass estimation method was used to calculate the per unit amount of Carbon that can be sequestered by Kakamega forest as well as the surrounding farms. Objective one will be achieved using this method.

The above-ground biomass of trees in general was measured by the following regression equation of biomass as a function of diameter at breast height (Brown et al., 1989):

$$Y = \exp\{-2.4090 + 0.9522 In(D^2 HS)\}$$

Where: Y is the above-ground biomass in tdm/ha

H is the height of the trees in meters (average height)

D is the diameter at breast height (1.3 in cm)

S is the wood density per hectare

Underground biomass is calculated as 15% of the above-ground biomass (MacDicken, 1997). The above-and under-ground biomass was added to get the total biomass of the stand.

The carbon content of trees was measured based on the biomass of trees with the following formula adapted from World Bank (1998):

Biomass carbon content (tdm/ha) = Biomass weight (tdm/ha) * 0.5 tC/tdm,

Where: tC stands for tons of carbon and tdm for tons of dm.

3.4 Approximation of economic value Carbon under CDM trading

This method helped in achieving objective two of the study.

The CDM was established by Article 12 of the Kyoto Protocol to create Certified Emissions Reduction (CERs), generated by projects in developing countries. It does not explicitly mention forest or land use but allows any project that has 'real, measurable and long-term benefits related to the mitigation of climate change' and that is 'additional to any that would occur in the absence of the certified project activity'. This is according to Kyoto Protocol. The CDM allows the possibility of trading carbon offsets from forestry or land-use projects (at least from reforestation and afforestation activities) through the Article 12 (the CDM or 'CERs' from developing countries), (Kyoto Protocol, 1997).The cost of carbon sequestration varies from region to region, and also from country to country, based on different economic analyses. Phat et al. (2004) estimated the cost of carbon at around US$ 19.7 per Mg C in Southeast Asian countries. Kirschbaum (2001) assumed a cost of US$ 10 per Mg C for indefinite carbon savings in different arbitrary accounting periods. Missfeldt and Haites (2002) used a 1995 cost of US$ 15 per Mg C for a sink enhancement scenario, and Tschakert (2002) used a cost of US$ 15 per Mg C for her study in Senegal. In other studies, it ranged from US$ 1 to 100 (Healey et al., 2000; CIDA, 2001; Niles et al., 2002).There is no study on prices of carbon credits from forests in Kenya but it can be assumed from the above findings that the price would range from US$ 15 per Mg C based on the scenarios in Southeast Asian countries and Senegal, assuming the same socio-economic conditions.

3.5 Empirical Model

An empirical model was used to achieve objective three of the study. This implies that the determinants of the total amount of carbon sequestered per hectare such as socio-economic characteristics, demographic characteristics, farm characteristics, number of trees, and age of trees were estimated using a tobit model. The dependent variable in the regression was the total amount carbon sequestered by farms per hectare. The independent variables used were:

$$CSEQ_i = \alpha_0 + \sum \delta_k FARM_K + \sum \varphi_l SOCIOECO_L + \sum \beta_j DEMOG_n + \varepsilon_I$$

Where:

CSEQi is the total amount of carbon sequestered by farm *i*. This takes the expression, *CSEQ*=1 or more upto the upper limit if the farm has ability to sequester carbon and, 0=otherwise.

α_0 is the constant term, β, δ, φ are the vectors of coefficients to be estimated; *FARMk* is a vector of farm characteristics variables; *SOCIOECOl* is a vector of socio-economics factors *DEMOGn* is a vector of demographic characteristics variables; and εi is the error term.

Model Specification:

$Y=\square_{0+}\square_1 X_1+\square_2 X_2+\ldots\ldots\square_{16} X_{16}+\varepsilon$……………………………………………(18)

Where $\square_0$ =constant; $\square_{1,}\ldots,$ $\square_{16}$=Coefficients to be estimated; Y= Total amount of carbon sequestered by farm *I* ;X_1= Total size of of land in acres;X_2= Year household acquired land;X_3= Tenure Status of the Main Farm;X_4= Area under Main Crop Farmed; X_5= Area under livestock grazing; X_6= Economic Activity of the household head;X_7= Trees used for timber;X_8= Gender of the Respondent ;X_9= Age of the Household Head in years;X_{10}= Education of the household head;X_{11}= Household Head;X_{12}=Membership to groups; X_{13}= Distance of farm to nearest market; X_{14}= Perception of farmer to climate change and forests.

The following prepositions presented in Table 3.1 were envisioned:

Table 3.1: Variables description, measurement and expected signs

Variables	**Descriptions**	**Units**	**Expected signs**
1. CSEQ	**Total Amount of carbon sequestered**	**Categorical**	**+**
2. FARM CHARACTERISTICS			
Landsize(X_1)	Total size of land in acres	Acres	+
Yearland (X_2)	Year household acquired land	Years	+
Mainfrmt X_3)	Tenure Status of the Main Farm	Numbers	+
Mainfncr(X_4)	Area under Main Crop Farmed	Acres	-
Mainfrmg(X_5)	Area under Livestock Grazing)	Acres	-
Activity(X_6)	Economic Activity of the Household Head	Dummy	-
Treeuse3(X_7)	Trees used for Timber	Dummy	-
3. SOCIO-ECONOMIC FACTORS			
Resposex(X_8)	Gender of respondent	1=Male 0=Female	+
Agehhd(X_9)	Age of the household head in years	Years	-
Educhhd(X_{10})	Education of the household head	Years of Schooling	+
HHSize(X_{11})	Household Size	Number	+
Membergrp(X_{12})	Membership in groups	Dummy	-
4. DEMOGRAPHIC CHARACTERISTICS			
Dist(X_{13})	Distance of farm to forest	Kilometers(KM)	+
Redglowm(X_{14})	Perception of farmer to climate change and forests	Dummy	-

3.6 Data analysis

The gathered survey data was entered into the LIMDEP computer program and both descriptive and econometric analytical procedures adopted for data management and analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter is divided into three sections. The first section discusses the results of the potential and economic value of carbon sequestration for Kakamega forest as well as the surrounding farms. The second section discusses the results of the descriptive analysis, which includes an overview of the socio-economic characteristics of the farm households surrounding Kakamega forest, household characteristics, and trees and climate change issues. Section three discusses the results of the econometric estimation of determinants of total amount of carbon sequestered per hectare.

4.1 Potential and Economic Value of Carbon Sequestration in Kakamega Forest and Surrounding Farms

4.1.1: Carbon Sequestration Potential

Biomass estimation method was used to calculate the amount of carbon that can be sequestered by Kakamega forest as well as the surrounding farms. Using the formula presented in the methodology, the total amount of carbon that can be sequestered by the undisturbed indigenous forest is 334Mg C/ha while of the surrounding farms is 203Mg C/ha. This gives a total of 537Mg C/Ha. It is notable that indeed the forest has a higher amount of carbon as compared to the farms.

Table 4.1: Carbon density (Mg C/ha)

Sampled Cover	Area (ha)	Carbon Density (Mg C/ha)
Undisturbed Old Indigenous Forest	12,070	334
Surrounding farms	6,600	203

Kakamega's indigenous rainforest carbon density of 334 Mg C/ha was similar to densities seen in the Neotropics, such as Amazonia 232 Mg C/ha (Fearnside 1997), and

Venezuela 386 Mg C/ha (Delaney et al. 1997), Panama 351 Mg C/ha (Chave et al., 2003), highlighting this land cover type as an important potential carbon store.

Table 4.2: Comparing Kakamega's old indigenous forest carbon density and carbon density estimates for mature Neotropical moist forests

Country/region	Carbon density (Mg C/ha)	Source
Amazonia	232	Fearnside (1997)
Panama	351	Chave et al. (2003)
Venezuela	386	Delaney et al. (1997)
Kakamega, Kenya	334	Survey(2007)

4.1.2: Economic Value of Carbon under CDM Trading

The clean development established by Article 12 enables estimation of the value of carbon. Since Kenya has not participated in any carbon trading under CDM, and there being no study on prices of carbon credits in Kenya, this study assumed from different findings in other countries stated in the methodology, that the price of carbon be US$ 15 per Mg C based on the scenarios in Southeast Asian countries and Senegal, assuming the same socio-economic conditions. The reason for this assumption is that since Kenya has not participated in any forest carbon trading, the price of carbon has not yet been established.

Thus, the economic value of carbon trading for Kakamega forest and its environs can be estimated. Given that the carbon sequestration potential for Kakamega forest is 334Mg C/ha, then the economic value of carbon trading is US$ 5010 per hectare. On comparison to that of the farms which is US$ 3045 per hectare, it implies that the forest has a higher capacity to generate revenue to the country if it participated in carbon trading.

It is good to note that KENGEN is already in negotiation to participate in carbon trading with World Bank from the carbon it emits from industrial processes. The bank will purchase one Certified Emission Reduction (CER) at price of US$ 10.5 for Olkaria II geothermal expansion, 13.9 US $ for Kiambere Optimisation, Redevelopment of Tana Power station and Eburru geothermal and 12.9 US $ Kipevu Combined Cycle and Sondu Miriu. This means that the projects will generate annual cash flow revenue to KenGen in the range of Kshs million 500 per annum up to the year 2012. But currently there is no price for carbon from forests.

Nevertheless, Carbon Manna Unlimited is pushing forward an ingenious pilot project that rewards small scale farmers in Mbeere and Bungoma districts for planting trees and using more energy efficient stoves, known locally as jikos, for cooking. To start of with, it is giving each family involved Sh 2,200 per month. A personal carbon emission trading offers a financial carrot to individuals or families to get them to clean up their act. The farmers involved in the project will be allowed to emit only a specified amount of carbon dioxide measured according to pre-agreed scale. If they cut their emissions below this limit, the balance is calculated in monetary terms and they are paid for it. The carbon credits payment is now in its trial stage. Carbon Manna will subsidise the purchase of the jikos in Kenya. This project falls under CDM executed in developing countries that cannot afford the technology required to lower carbon emissions

4.2 Descriptive Results

4.2.1 Household Characteristics

Table 4.3: Household Head Summary Statistics

Variable	Minimum	Maximum	Mean
Age of the household head in years	20.00	87.00	51.1
Years of formal education	.00	18.00	7.8
Household Size	1.00	12.00	5.2

Some of the household related characteristics are presented in Table 4.3. The average household size across the entire sample is 5.2 adult equivalents. This is comparable to the average Kenyan household size of 5.2 reported by the Ministry of Planning in the Welfare Monitoring Survey Report (1996).

Table 4.4: Household head Characteristics

Variable	Male	Female
Sex of household head (%)	75.7	24.3
Average age (years)	51.2	47.6
Average number of education years	7.8	7.6

Table 4.4 shows the characteristics of the household head in the study area. The household head is defined as the senior member of the household who makes key decisions in the household and whose authority is acknowledged by other members. The results indicate a predominance of households headed by males as opposed to females. 75.7% of the households interviewed were male headed households while 24.3% were female headed households. This implies that most decisions made regarding land use such as planting trees are made by the males.

The average age of the household head in male and female headed households is 51.2 and 47.6 years respectively. The female headed households have lower education levels compared to their male headed counterparts. Generally, women are less educated and handle fewer employment opportunities as compared to their male counterparts. They therefore have fewer alternative avenues for off-farm income, to meet household needs.

4.2.2 Socio-Economic Characteristics

Crop production was the main economic activity (45.7%) undertaken by the households followed by formal (15.7%) and casual (14.3%) employment. Self employment (11.4%) is also another economic activity of the households. Livestock production and sale of fuel wood is not a major economic activity. Some households preferred to combine some these economic activities together so as to earn a living. The results further indicate that 64.3 percent of the households engaged in the crop production, employment, livestock production, and sale of fuelwood for food and income purposes. Additionally, 23.1 percent engage in economic activities for food only and 12.1 percent for income reasons.

Table 4.5: Socio-economic Characteristics

Economic Activity	Frequency	Percentage (%)
Crop Production	64	45.7
Casual Employment	22	15.7
Formal Employment	20	14.3
Self Employment	16	11.4
Both Crop Production & Self Employment	9	6.4
Livestock Production	3	2.1
Both Crop & Livestock Production	3	2.1
Sale of Fuel wood	2	1.4
Both Crop Production & Formal Employment	1	0.7
Total	**140**	**100.0**

The main source of income for most households comes from casual employment and sale of farm produce. Other sources included self employment, formal employment and sale of fuel wood. Further 50 percent of the land owned by the households was titled, 47.9 percent was not titled, while 2.1 percent was rented. The method of acquisition of the land was that 86.4 percent was inherited, 12.9 percent bought and 0.7 percent was given as gifts. This provides an overview of the type of decisions made on the farms. A person with a piece of land that is not titled may be hesitant in doing major investments and improvements on the farm such as tree planting as they do not have the title yet.

4.2.3: Trees and Climate Change Issues

The survey results indicate that of the total land size in the study area, 97.1 percent of the farms had planted trees while 2.9 percent had not. This is a sure indication of the extent to which the farms can help in carbon sequestration. The survey further shows that out of this the farms that had planted trees, majority of them had mature trees that can sequester more carbon. This finding corroborates observations by Glenday J. (2005) on carbon storage and emissions offset potential in an East African tropical rainforest. The study showed that old indigenous mature forest plots within 2 km of a forest station and had a significantly higher average carbon density (690±130 Mg C/ha) than those at greater distances (340±30 Mg C/ha, $p = 0.001$). Distance of the farm to the nearest market or centre is a variable that can be attributed to this variability. This can be interpreted to mean that the nearer the market the more likely people will afford to buy other alternatives to fuelwood hence trees in the farm will not be felled easily.

Table 4.6: Awareness of Climate Change Issues

Variable	Percentage (%)
Aware	85.7
Unaware	8.6
Uncertain	5.7

Table 4.6 shows the level of awareness of issues to do with climate change by the respondents interviewed. From the survey, 85.7 percent of those interviewed were aware of issues to do with climate change, 8.6 percent were unaware and 5.7 percent were

uncertain. This is a good indication that efforts to intensify own farm tree planting may be successful.

Table 4.7: Perception on Reduction of Global Warming Using Trees

Variable	Percentage (%)
Strongly Agree	46.4
Agree	46.4
Neutral	6.4
Strongly Disagree	0.7

Table 4.7 summarises perception of the households on whether trees can help in reducing global warming. When asked about the perception as to whether trees can help in reducing global warming, 46.4 percent strongly agreed, 46.4 percent agreed, 6.4 percent were neutral and another 0.7 percent strongly disagreed. This implies 92.8% of the people are aware that trees can be used to reduce global warming.

At present, global warming is a matter of grave concern. Since the late 19th century, the global temperature has increased by 0.3–0.61C, and, globally, sea levels have risen 10–15 cm over the past 100 years (IPCC, 1995). Due to over-population, especially in African countries, natural resources are under extreme pressure, which, cumulatively, is causing environmental problems.

4.3 Estimated Econometric Results

A tobit model was estimated with the dependent variable being the total amount carbon sequestered by trees in the farms. The objective was to identify the determinants of the total amount of carbon sequestered. Independent variables consisted of socio-economic characteristics, demographic characteristics, farm characteristics, number of mature trees, age of trees, and awareness of issues to do with climate change. The description of the results of the independent variables is presented in Table 4.8 in page 31. Standard errors of β estimates were examined to assess possibilities of multicollinearity.

Table 4.8: Estimated Tobit model for the determinants of amount of carbon sequestered by trees in farms.

Variable	Maximum Likelihood Coefficient	Standard Error	P[|Z|>z]
CONSTANT	66.7491*	22.9402	0.0036
RESPOSEX	-323883*	16.3052	0.0470
HHSIZE	-0.0073	0.03636	0.8418
EDUCHHD	0.03701*	0.0220	0.0921
ACTIVITY	20.9300	14.7152	0.1549
YEARLAND	0.0007	0.00828	0.9314
MAINFRMT	27.1706*	12.8199	0.0341
MAINFRNCR	4.0393	3.1540	0.2003
MAINFRMG	0.0883	0.1509	0.4043
TREEUSE3	18.0823	14.2229	0.2036
DISTANCE	0.0158	-0.0393	0.6883
REDGLOWM	-5.3140	14.3997	0.7121
MEMBERGRP	-3.1518	7.3955	0.6700

**=Significance level at, 5%, respectively.

Number of observations = 120

The maximum likelihood coefficients indicate that sex of the respondent (RESPOSEX, 0.0470), education of the household head (EDUCHHD, 0.0921), and tenure status of the farm (MAINFRMT, 0.0341), have a significant influence in determining the probability of the amount of carbon that can be sequestered by trees in the farms. This implies that a farm that is titled is more likely to have more trees than one which is not titled. So policy makers should put in place measures to ensure that most farms are titled so as to encourage people to plant more trees. Education level of the household head is also a key determinant of the amount of carbon that can be stored by farms. Therefore people need to be educated more on the importance of planting trees with emphasis on the ability to sequester carbon thereby reducing global warming which in turn will help in agricultural sector because of less impact of global warming.

The coefficient of household size (HHSIZE, -0.0053) has a negative influence on the probability of the amount of carbon sequestered. This implies that as the household size increases, the amount of carbon that can be sequestered by trees decreases. People tend plant less tress as the household size increases as there are more pressures on the land such that planting trees does not become a priority. Instead, people opt to grow crops and keep livestock on the farms so that they can be able to cater for the needs of the large household size. There is also the tendency to fell the trees for wood fuel by large households.

On the other hand, the coefficients on education of the household head (EDUCHHD 0.03701), economic activity for the household (ACTIVITY, 20.9300), year household acquired land (YEARLAND 0.0007), tenure status of the farm (MAINFRMT, 27.1706), area under crops (MAINFNCR, 4.0393), area under livestock (MAINFRMGR, 0.0883), trees used for timber (TREEUSE3, 18.0823) and distance to the forest (DISTANCE 0.0158) were strongly positively significant ($p<0.05$) in determining probability of the amount of carbon sequestered. This positive signs were *a priori* expected. This implies that trees were perceived to be of greater value by household heads that were educated. This can be attributed to the fact that they are more knowledgeable compared to their counterparts who are not educated. In addition, trees were perceived to be of greater value by household heads as their age increases. Similarly, the older the land is in terms of acquisition, the older the trees; hence they have matured and therefore have higher ability to sequester more carbon. A study by Shin et al (2004) in Bangaldesh corroborates to these findings. The study revealed a difference in carbon storage between indigenous forest and hardwood plantation due to the age distribution within the different forest classes: the hardwood plantation area was 70% young with low carbon, while the indigenous forest was 89% old.

The study also indicates that households engaged in economic activities earn income and hence plant trees in their lands because their sources of income are diverse and not only from land use. Distance of the farm to the nearest market or centre also influences the amount of carbon sequestered positively. This can be interpreted to mean that the nearer the market the more likely people will afford to buy other alternatives to fuelwood hence trees in the farm will not be felled easily.

4.9 Descriptive Statistics of Explanatory Variables

Variable	**Mean**	**Std Deviation (SD)**
RESPOSEX	0.8	0.4303
HHSIZE	5.2	2.1422
EDUCHHD	7.8	3.8827
ACTIVITY	0.6	0.4993
YEARLAND	1983	16.3593
MAINFRMT	0.1	0.5426
MAINFRNCR	2.3	2.1336
MAINFRMG	0.4	0.5082
TREEUSE3	0.5	0.4999
DISTANCE	3.0	2.7550
REDGLOWM	0.5	0.5005
MEMBERGRP	0.7	0.9268

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The East African indigenous rainforest found in Kakamega supports high levels of biodiversity and provides sundry ecosystem services to Western Kenya. In addition, as a high carbon density land cover type, it can provide a global service as carbon store helping to mitigate climate change. While past human disturbances have reduced forest areas and depressed forest carbon densities, the results of this study illustrate the potential economic value of carbon storage in the Kakamega National Forest economically.

The study shows that Kakamega forest makes a significant contribution to carbon sequestration and therefore can generate carbon credits in Kenya. It is also expected that much revenue can be earned by selling carbon credits in the carbon market through CDM projects. Forestry lands, used under the CDM, would provide benefits to the national forestry sector, as well as the private owners and participants in the community forestry, in terms of an overall increase in income, and self-sufficiency.

5.2 Policy Implications

Appropriate economic institutions and mechanisms need to be established for the CDM to result in equity and sustainable development. The effects of global warming in Kenya, show serious consequences on the economy. The quantification of carbon sequestration, by this study, can direct policymakers, researchers, and administrators in bargaining for the price of international greenhouse gas reduction, which can advance the economic, social and environmental development of Kenya. The study may also be useful to possible investors in CDM projects in Kenya. Another important aspect of this study is that it also possible to use the farms to sequester carbon from the atmosphere by practicing agroforestry, as this has proved to be a vital way carbon sequestration. Policy makers should put in place measures to ensure that most farms are titled so as to encourage people to plant more trees. Education level of the household head is also a key determinant of the amount of carbon that can be stored by farms. Therefore people need to be educated more on the importance of planting trees with emphasis on the ability to sequester carbon thereby reducing global warming which in turn will help in agricultural sector because of less impact of global warming.

5.3 Recommendations

Based on the results of the work carried out, several recommendations have been made.

1) Research should be undertaken to collect data on the quantity, distribution and partitioning of carbon, and any changes taking place over time in the different sections of the forest such as indigenous and the disturbed forest, as well as the planted trees by farmers.
2) Community involvement and analysis of other options such as agroforestry by farms to help increase carbon storage by trees and other plants needs to be researched on extensively.
3) A strong long-term political commitment by the government to prevent logging, deforestation, to manage and protect the remaining natural forests (natural production forests and protected areas) is required as a high priority.
4) The problem of market for carbon and finding a buyer should be addressed extensively.
5) Research on how to develop formulae for the cost of Mg of Carbon in Kenya.
6) The local community should be discouraged from destroying the natural indigenous Tropical forests.

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APPENDICES

APPENDIX I: Survey Questionnairre

EGERTON UNIVERSITY

A SURVEY ON FARMS AROUND KAKAMEGA FOREST IN RELATION TO CARBON SEQUESTRATION POTENTIAL

THE INFORMATION GIVEN IN THIS QUESTIONNAIRE WILL BE HANDLED CONFIDENTIALLY AND WILL BE USED FOR RESEARCH PURPOSE ONLY.

Questionnaire identification

Questionnaire No ………… Date…………..

Enumerator: ……………… Code……….

District …………………… Code……….

Division…………………… Code……….

Location…………………… Code……….

Sub-Location……………… Code……….

Village……………………. Code……….

SECTION A: BACKGROUND INFORMATION

1. (a) Name of respondent……………………

Gender of respondent 01=Male [ ] 02= Female [ ]

(b) Respondent's position in the household

01=Husband [ ]

02=Wife [ ]

03=Son [ ]

04=Daughter [ ]

05=Household help [ ]

06=Other (Specify) …………………

2. Name of the household head (if different from respondent)……………………….

Gender of the household head 01=Male [ ] 02= Female [ ]

3. Household size (people living in the household over the last one month) …………

4. Age of the household head………………………………………………………..

5. What level of education have you attained?

Primary	[01]	Tertiary	[03]	None	[05]
Secondary	[02]	University	[04]		

SECTION B: SOCIO-ECONOMIC ACTIVITIES

6. What is the main economic activity household head is engaged in?

01= crop production 02= livestock production

03= selling of forest products 04= formal employment

05= casual employment 06= other (specify) ……………….

7. What is the main reason of engaging in the above activity?

01=income 02=food source

03=production of breeding stock 04=other (specify)……………

8. What is the main source of food for your household?

01=own-farm production

02=purchased

03=other (specify) ……………………

9. What is the main source of income for this household?

01=sale of farm produces 02= sale of forest products

03=formal employment 04=casual employment

05=remittances 06=other (specify) …………………

10. (a) Do the household posses any livestock?

01=yes 02=no

(b) If yes, fill in the table below

Table 1

Livestock type	**Number(s)**	**Where grazed**
Indigenous cows		
Grade cows		
Goats/sheep		
Donkey		
Bees(hives)		

<u>Where grazed</u>
01=forest
02=zero grazed
03=open fields
04=other (specify)

SECTION C: FARM AND DEMOGRAPHIC CHARACTERISTICS

11. Which year did you establish your main farm? …………………..

12. What is the total size of land/farm (in acres) owned by this household? ……………

13. Do you own this land/farm?

14. How did household acquire access to this land?

01=inherited	02=bought
03=rented in	04=gift
05=government allocation	06=shamba system
07=free access	08=other (specify)

15. Which year did household acquire this land? (Year)……………….

16. How much of your land is under?

Cultivation…….acres	Pasture……..acres
Homestead…….acres	other (specify) ……acres

17. For cultivation, which crops do you grow in this land?

01=growing annual crops	02=growing perennial crops
03=both	04=other (specify)

18. Does this land type have any trees?

01=yes 02=no

19. If yes, what are the trees on the household's land used for?

01=fuel wood	02=charcoal
03=timber	04=fence boundary
05=wind breakers	06=other(specify)

SECTION C: FOREST PLANTATION, TREE SPECIES CHARACTERISTICS

19. Do you have any trees that you have planted in your farm?

01=yes 02=no

20. What is the age of the trees in your farm?..

21. How many mature trees do you have in this farm?...

22. What is your reason for planting the trees?..

23. What is the distance of your farm to the forest?...

24. Are you aware of issues to do with climate change?

Aware [01] Uncertain [02] Unaware [03]

25. Do you think that planting trees can help reduce global warming?................................

Strongly agree [01] Agree [02] Neutral [03] Disagree [04] Strongly Disagree[05]

APPENDIX II: Estimation Results of Tobit model for the determinants of amount of carbon sequestered by trees in farms.

TobitTruncation;Lhs=Cseq;Rhs=One,Resposex,Hhsize,Educhhd,Activity,Mainfrmt, Mainfncr,Mainfrmg,Treeuse3,Redglowm,Membergr;Limits=0,295.82$

```
+----------------------------------------------------------------------+
| Limited Dependent Variable Model - TOBIT TRUNCATED Regression
|
| Ordinary    least squares regression    Weighting variable = none
|
| Dep. var. = CSEQ     Mean=   88.06333333    , S.D. =   51.67230477
| Model size: Observations = 84, Parameters =13, Deg.Fr. =73
| Residuals:  Sum of squares= 175953.3035, Std.Dev.=49.9500
| Fit:R-squared=.207885, Adjusted R-squared =.07401
| Model test: F[ 12,73] =1.89,    Prob value =.05960
| Diagnostic: Log-L =-440.3714, Restricted(b=0) Log-L =-450.0613
|             LogAmemiyaPrCrt.=7.911, Akaike Info. Crt.=10.747
+----------------------------------------------------------------------+
+---------+-------------+----------------+--------+---------+---------
|Variable | Coefficient | Standard Error |b/St.Er.|P[|Z|>z] |Mean of X|
+---------+-------------+----------------+--------+---------+--------+
 Constant  79.18853744      17.919268        4.419   .0000
 RESPOSEX -25.25019568      13.347020       -1.907   .0565 .72619048
 HHSIZE    .5337464871E-02  .27790090E-01     .192   .8477 -42.666667
 EDUCHHD   .2670436676E-01  .16611438E-01    1.587   .1125 -160.16667
 ACTIVITY  15.32454556      11.563949        1.325   .1851  .57142857
 YEARLAND  .1085384053E-03  .15071685E-01    .0720   .4714  1770.8143
 MAINFRMT  20.4050894      10.290094        1.983   .0474  .60714286
 MAINFNCR  3.242134141      2.6648465        1.217   .2237  2.3184524
 MAINFRMG  .3910060631E-01  .50879279E-01     .768   .4422 -11.544048
 TREEUSE3  14.07391766      11.364190        1.238   .2156  .50000000
 DISTANCE -.2804572570E-01  .60873667E-01    -.046   .9633 -39.997857
 REDGLOWM -4.029352482      11.622988        -.347   .7288  .47619048
 MEMBERGR -2.132332402      5.0540009        -.422   .6731  .71428571
+---------+-------------+----------------+--------+---------+--------+

Normal exit from iterations. Exit status=0.
```

```
+---------------------------------------------+
| Limited Dependent Variable Model - TRUNCATE |
| Maximum Likelihood Estimates                |
| Dependent variable                CSEQ      |
| Weighting variable                 ONE      |
| Number of observations             120      |
| Iterations completed                 5      |
| Log likelihood function      -434.6539      |
| Threshold values for the model:             |
| Lower=     .0000     Upper=295.8200         |
| Observations after truncation       84      |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Primary Index Equation for Model					
Constant	66.74911280	22.940202	2.910	.0036	
RESPOSEX	-32.38835336	16.305214	-1.986	.0470	.72619048
HHSIZE	.7256284082E-01	.36362867E-01	.200	.8418	-42.666667
EDUCHHD	.3700647640E-01	.21967643E-01	1.685	.0921	-160.16667
ACTIVITY	20.93004839	14.715297	1.422	.1549	.57142857
YEARLAND	.7133255329E-03	.82850116E-01	.086	.9314	1767.8571
MAINFRMT	27.17064018	12.819895	2.119	.0341	.60714286
MAINFNCR	4.039368811	3.1539802	1.281	.2003	2.3184524
MAINFRMG	.8834710451E-01	.10593786	.834	.4043	-11.544048
TREEUSE3	18.08229930	14.222882	1.271	.2036	.50000000
DISTANCE	.1578274058E-01	.39336114E-01	-.401	.6883	-44.828571
REDGLOWM	-5.314041769	14.399737	-.369	.7121	.47619048
MEMBERGR	-3.151854522	7.3955291	-.426	.6700	.71428571
Disturbance standard deviation					
Sigma	52.80031939	5.8298546	9.057	.0000	

APPENDIX III: Descriptive Statistics of the determinants of amount of carbon sequestered by trees in farms.

```
DSTAT;Rhs=ONE,RESPOSEX,HHSIZE,EDUCHHD,ACTIVITY,YEARLAND,MAINFRMT,MAINFN
CR,MAINFRMG,TREEUSE3,DISTANCE,REDGLOWM,MEMBERGR$
```

Descriptive Statistics

All results based on non missing observations.

Variable	Mean	Std.Dev.	Minimum	Maximum
RESPOSEX	.757142857	.430349173	.000000000	1.00000000
HHSIZE	5.23880597	2.14223236	1.00000000	12.0000000
EDUCHHD	7.75833333	3.88272588	.000000000	18.0000000
ACTIVITY	.550000000	.499280057	.000000000	1.00000000
YEARLAND	1983.87692	16.3593443	1935.00000	2007.00000
MAINFRMT	.521428571	.542679962	.000000000	3.00000000
MAINFNCR	2.26438849	2.13361845	.000000000	12.0000000
MAINFRMG	.378057554	.508162187	.000000000	3.00000000
TREEUSE3	.457142857	.499948610	.000000000	1.00000000
DISTANCE	2.94253731	2.75503304	.500000000E-01	12.0000000
REDGLOWM	.464285714	.500513611	.000000000	1.00000000
MEMBERGR	.700000000	.926818648	.000000000	10.0000000

APPENDIX III: **Photographs of Kakamega Forest and Farms**