OPTIMIZING BIOMASS IN COMMUNITY BASED FOREST MANAGEMENT FOR CLIMATE CHANGE MITIGATION

A CASE STUDY OF IRINGA REGION, TANZANIA

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

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EXTENDED ABSTRACT

This study was conducted in Iringa Region, Southern Highlands of Tanzania. The objective was to optimize biomass under Community Based Forest Management (CBFM) in miombo woodlands for climate change mitigation and local livelihoods. By using optimization techniques with the aid of Excel solver computer software the optimization was performed. Six forest management options were created; (1) Business as usual (BAU), (2) Community Based Forest Management (CBFM), (3) total protection for carbon credit (CCO), (4) strict quota (SQ), (5) medium quota (QM), (6) loose quota (LQ) on miombo woodlands extraction.The study sought optimal biomass management options from local community point of view considering financial returns, CO_2 storage and sequestration and forest product extraction. Data were collected using pre-tested and pilot-tested questionnaires, direct observations, interviews and focus group discussions. Ecological datawere collected through satellite images for before and after CBFM intervention to provide extent of miombo woodland cover change while forest inventory techniques from with and without CBFM intervention provided status of biomass improvement.Accordingly the study explored the state of art in miombo woodland management; and growth and carbon storage potentials, presented as paper I. In addition the study examined land use and cover change in miombo woodlands as influenced by community based forest management and its implication to climate change mitigation paper II. It was revealed that carbon stock improved significantly under CBFM compared to BAU ($P<0.05$). The cover change and land use analysis showed increase in cover density after CBFM than before, with decreasing unsustainable utilization. The improved carbon stock was subjected to the emerging voluntary carbon market and its implication on local livelihoods established (paper III). The carbon project feasibility analysis showed carbon trading is feasible based on internal rate of return and therefore carbon business is worth doing than ignoring (paper IV). Optimized biomass for carbon stock in miombo woodlands under CBFM developed as manuscript to be published (paper V). Based on this study biomass under CBFM is thus recommended to be optimized in addressing both climate change and livelihood challenges.

DECLARATION

I, ZACHARIA JOHN LUPALA, do hereby declare to neither the Senate of Sokoine University of Agriculture that, this thesis is my own original work, done within the period of registration and that it has neither been submitted nor being currently submitted in any other institution.

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The above declaration is confirmed by:

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DEDICATION

This work is dedicated to the family of Mr & Mrs Zacharia and to the memories of my late mother Veronika, father John and brother Christopher for the gift of love to me.

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Paper II: Lupala, Z. J., Lusambo, L.P., Ngaga, Y.M and Angelingis A. Makatta., 2015. The Land Use and Cover Change in Miombo woodlands under Community Based Forestry Management and its implication to climate change Mitigation. A case of Southern Highlands of Tanzania. *International Journal of Forestry Research*.DOI: 10.1155/2015/459102.

Paper III: Lupala, Z. J., Lusambo, L.P., Ngaga, Y.M., 2015. Potential of Voluntary Carbon Markets for Improved Carbon stock in Community Based Forest Management of Miombo woodlands, Tanzania. *Journal of Global Ecology and Environment, ISSN No. 2454-2644.Vol. 3 Issue 4.*

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Paper V: Lupala, Z. J., Lusambo , L.P., Ngaga. , Y.M and Makatta, A. A. (2017). Optimising Biomass in Community Based Forest Management for climate change mitigation and local livelihoods in Tanzania. *Manuscript*.

LIST OF ABREVIATION AND ACRONYM

AGB	Above Ground Biomass
BAU	Business as usual
BGB	Below Ground Biomass
CBFM	Community Based Forest Management
CCO	Carbon Credit Only
FAO	Food and Agriculture Organization of United Nations
FGD	Focus Group Discussion
GPS	Global Positioning System
Ha	Hectare
HH	Household Head
IPCC	Intergovernmental Panel on Climate Change
JFM	Joint Forest Management
LQ	Loose quota
MNRT	Ministry of Natural Resources and Tourism
NPV	Net present value
NTFP	Non Timber Forest Products
PFM	Participatory Forest Management
PRA	Participatory Rural Appraisal
QM	Medium quota
REDD/REDD+	Reduced Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
REDD+	Reduced Emissions from Deforestation and forest degradation

SQ	Strict quota
UNFCCC	United Nations Framework Conference on Climate Change
URT	United Republic of Tanzania
VLFR	Village Land Forest Reserve

WORKING DEFINITIONS OF SELECTED TERMS

Wood fuel:	Firewood and/or charcoal
Household income:	Total income from all household members with exception of *maids* and *servants* of that respective household.
Household members:	People living and eating together for at least one month before this study was carried out
Charcoal:	A carbonaceous material obtained by heating wood in the earth- mound kiln, in the absence of air.
CBFM	Forest resources owned and managed by local communities through village environmental committees
PFM	Is the collaborative forest management regime involving state and local Communities, includes both Joint forest management and Community based forest management
BAU	Business as usual forest or woodlands found in village general lands and is used as open access forest without any local bylaws and or management plan controlling its extraction activities

DECLARATION OF THE PAPERS

I, **Zacharia John Lupala**, do hereby declare to the Senate of Sokoine University of Agriculture that the listed papers that make this thesis summarise my independent efforts and they constitute my own original work and they will not be part of another thesis in any other University.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Miombo woodlands are distinguished from other African forest formations by the dominance of tree species in the family *Fabaceae,* subfamily *Caesalpinioideae* and genera *Brachystegia*, *Julbernardia* and *Isoberlinia* (Campbell *et al.,* 2007). These ecosystems dominate in the African continent (Campbell *et al.,* 2007; FAO, 2010; Schimel, 2010; Chidumayo, 2013; Lupala *et al.*, 2014). According to Bond *et al.,* (2010), miombo woodlands cover between 2.7 and 3.6 million km from eastern and southern Africa. The woodland has plant diversity of over 8500 species (Frost, 1996) and provides habitat for wildlife reserves (Bongers and Tennigkeit, 2010). Miombo woodlands also account for about 30% of the primary production of all terrestrial vegetation (Mugasha *et al.*, 2014).This woodland plays crucial role in energy, local livelihoods and carbon storage (Schimel, 2010; Lupala *et al.*, 2014). In Tanzania miombo woodlands supports about 87% of rural livelihoods (Abdallah and Monela, 2007), 90% national energy supply (Lusambo, 2009) and 75% construction materials (Miles *et al.*, 2009). The woodland is an integral part of the habitat, socio-cultural and economic strategy in Tanzania (Milledge *et al.,* 2007; Abdallah and Monela, 2007; Lupala *et al.*, 2014).

This vegetation type provides critical life-support function to people and biodiversity through various goods and services (Bongers and Tennigkeit, 2010; FAO, 2009). Carbon storage and sequestration is among the important services (Lupala *et al*., 2014; Bond *et al.,* 2010, MNRT, 2010). The alarming rate of deforestation and forest degradation in tropical forests including miombo woodlands threaten this function (FAO, 2009; Bongers and Tennigkeit, 2010). Deforestation implies a forest area is cleared, becoming non-forests, i.e. canopy cover falls below threshold level in the range of 10-30% (FAO, 2010;

Putz, 2010). Although degradation refers to decrease in density of forest biomass, the how to be measured is yet unclear (Putz, 2010; Hosonuma *et al*, 2012). Scholars often use the terms interchangeably (Bongers and Tennigkeit, 2010; Chidumayo, 2013), a clear definition is greatly needed (Putz, 2010; Fabians*et al.*, 2011). Deforestation and forest degradation contributes about 18-25% of global green house gas emission (Stern, 2007; Angelsen and Hofstad, 2008). Africa alone account for nearly 70% of the total emission (Stephens *et al*., 2007, Gibbs *et al.,* 2007).

Miombo woodlands suffer more severe from deforestation and forest degradation if compared to other forest biomes (Campbell *et al.,* 2007; Mwase *et al.* 2007; Fabiano *et al.*, 2011). This has been causing social, economic and environmental consequences, including global warming (UNFCCC, 2007; Gibbs *et al.,* 2007). For example, Tanzania had 41.5 million ha of forests in 1990s, decreased to 37.5 million ha in 2000, thereafter to 33.4 million ha in 2010 (FAO, 2010). Annual deforestation and forest degradation rate is about 372,871 ha annually (URT, 2015). This corresponds to annual loss of about 1%, which emits about 100 million tons of greenhouse gas annually (Milledge, 2007).This trend raises concern about the future capacity of miombo woodlands to provide goods and services (Chidumayo, 2013; Lupala *et al*., 2014).

The global policy mechanism to reduce emission from deforestation and forest degradation and the role of conservation, sustainable management and enhancement of forest carbon stock (REDD+) is proposed to be the policy option for this problem (Angelsen, 2008; Peskett *et al.,* 2008; Laurence, 2009; UN-REDD, 2009). REDD+ was designed to encourage developing countries to minimize the rate of deforestation and forest degradation in exchange of tradable abatement credits financed by developed countries (Angelsen, 2008; Karsenty, 2008). It seeks to recognise the value of carbon stored in forests and shift incentive from deforestation and forest degradation to forest conservation and management (Larson and Petkova, 2011). The objective of REDD+ is to serve as a link between climate change mitigation, sustainable forest management and poverty alleviation (Angelsen, 2008; UNFCCC, 2007; Laurence, 2007).

Over the past years, many developing countries have strived to establish REDD+ preparatory activities (UN-REDD, 2009; Norman and Nakhooda, 2014). This includes developing national REDD+ strategies, building capacity and systems for monitoring and reporting (UNFCCC, 2007; Bofin *et al*., 2011). They also have piloted REDD+ projects to demonstrate its potential (Angelsen, 2008; Norman and Nakhooda, 2014). Most of these pilot REDD+ projects were built on community based forest management framework (Zahabu, 2008; Chahatre and Agrawal, 2009; Karky and Skutsch, 2010). For example, in Tanzania five out of nine projects used community-based forest management approaches as a basic underlying strategy (Zahabu, 2008; Bofin *et al*. 2011; Robinson *et al.,* 2013). Community based forestmanagement is believed to deliver social, economic and environmental benefits (Pfaff *et al.,* 2007; Peskett *et al.,* 2008; Phelps *et al.,* 2010; Robinson *et al.,* 2013).

Community forestry has a long history across the African continent (Tacconi, 2007). For centuries, communities have managed forests and woodlands traditionally, as a means to regulate the use of timber and non-timber forest resources (World Bank, 2004; FAO, 2007). They also conserve and extend grazing areas and maintain important cultural, spiritual or historical sites, such as “sacred forests” (Roe *et al.* 2009; Alden Wily 2012). Community owned and managed forests comprise more than 10% of the forests globally (Sunderlin *et al.,* 2008). The extent of forests used by local communities is close to 18% (Chhatre and Agrawal, 2008; Gibbs *et al*., 2007). To-date, community based forest management is a central policy in many developing countries (Taccon, 2007; Bowler *et al.,* 2012; Mustalahti and Lund, 2010). Among the successful community based forest management in Tanzania is largely implemented in miombo woodlands (Zahabu, 2008; MNRT, 2008).

In this study CBFM is referred to be *de-jure* government approved form of forest management by local communities. The practice should provide local communities with social and economic benefits whilst promoting sustainable forest management. There must be some degree of control and decision-making power vested in the community by the government or other designated authorities (Kajembe *et al.,* 2009; Blomley, 2013). The management should provide full ownership of the forest resource to local community (Blomley, 2013). Local community should have right to sustainable management and utilization of forest products such as fire wood, fodder, medicinal plants, mushroom and fruits and in some cases also timber (Zahabu, 2008; Treue *et al.,* 2014).

Various scholars have revealed climate change mitigation strategy through community based forest management as the most cost–effective option (Angelsen, 2008; Laurence, 2009). Based on these facts, REDD+ is currently the most prominent international mechanism to mitigate climate change and support local livelihoods (Angelsen *et al.,* 2009; Harvey *et al.,* 2010; Sandker *et al.,* 2010). REDD+ policy option might provide important incentive to CBFM in Tanzania as elsewhere (Zahabu, 2008; Treue *et al.,* 2014). However it needs synergistic balance to safeguard local livelihoods (Perez, *et al.,* 2007; Karsenty, 2008; Treue *et al.,* 2014; Lupala *et al.,* 2014).

Despite of this, knowledge on how community based forest management should be optimised in the light of climate change mitigation and local livelihoods option is yet unclear (Agrawal and Redford, 2006; Meshack and Raben, 2007; URT, 2009a; Middleton *et al.,* 2011). Knowledge of howto optimize yields of goods (i.e. Fuel woods) and services (i.e. carbon storage) from miombo woodlands to ensure their sustainability is scanty (Campbel, 1996; Ciais *et al.,* 2008; Mugasha, 2014; Araya and Hofstad, 2014).Several authors have recommended optimisation of CBFM for both climate change mitigation and local livelihood in miombo woodlands of Tanzania (e.g. Treue *et al.,* 2014; Mugasha, 2014; Araya and Hofstad, 2014; Lupala *et al.,* 2014).

The optimisation analysis could reduce the persisting rate of deforestation and forest degradation in tropical forests and particularly miombo woodlands (FAO, 2008; Campbell *et al*., 2008; Bongers and Tennigkeit, 2010; Fabiano *et al.*, 2011). Optimisation can facilitate the assessment of broader, wider- ranging trends, influences and management impacts to more adequately understand economic and ecological sustainability (Buongiorno *et al*., 2012). The knowledge is important, for example in the design of policy instruments that can achieve given level of forest protection for carbon offset and local livelihoods, or evaluating REDD+ feasibility and cost-effectiveness (Fisher, 2010; Angelsen and Hofstad, 2008).

1.2 Problem Statement and Justification of the Study

1.2.1 Problem statement

Forests and woodlands management for multiple uses is now becoming evident under global climate change mitigation strategies (UNFCCC, 2007; 2009). Climate change mitigation strategies such as REDD+ are expected to benefit much from forest management options practiced in miombo woodlands in Tanzania (Zahabu, 2008; Lund and Treue, 2008, Lupala *et al.,* 2014). However, there are conflicting views about the best ways to implement REDD+ initiatives for both climate change mitigation and livelihood improvement (Vatn *et al.,* 2009; Angelsen, *et al.,* 2008; Lupala *et al.,* 2014).

Limited knowledge exists on how to optimize current management options for both local livelihoods and climate change mitigation (Buongiorno *et al*., 2012; Sangeda, 2013). Policy makers are faced with uncertainty about the desirability and effectiveness of REDD+ initiative in management options for climate change mitigation scenario (Angelsen, *et al.,* 2008). In particular, whether forests that contribute more to local livelihoods such as miombo woodlands can be optimised for more or less carbon storage is yet unclear (Peskett *et al.,* 2008; Perez *et al.,* 2007; Vatn *et al.,* 2009). The knowledge of optimal biomass management options are not yet established for miombo woodlands ecosystem (Ciais *et al.,* 2008; Ahrends, 2010; Bond *et al.,* 2010; FAO, 2008).

Furthermore, the increasing concern that community based management in miombo woodlands in Tanzania provides limited tangible incentive to support local livelihoods is also pertinent (Lund and Treue, 2008; Zahabu, 2008). This concern compromises the sustainability and up scaling of the community based management to other parts of miombo woodlands facing deforestation and forest degradation (Bromley and Iddi, 2009; Vyamana, 2009). Little have been done to explore the rapidly emerging voluntary global carbon markets to provide tangible incentive for local livelihoods (World Bank, 2008; Fisher *et al.,* 2011). This could be due to little information on the extent of biomass for carbon stock and its potential to the emerging voluntary carbon markets. There is little understanding on how to optimize biomass management in miombo woodlands in Tanzania which can be harnessed for voluntary carbon markets and the implication of this to local livelihoods is also overarching challenge.

1.2.2 Study justification

The optimisation approach can capture the existing interactions between forest management, local livelihoods and climate change mitigation potential (Chhatre and Agrawal, 2009). This can further predict future scenarios given climate change mitigation policy and strategies. It can also ensure maintenance and enhancement of long-term socio-economic benefits based on climate change mitigation objectives. Optimisation analysis can be used to help develop goals and target incentives in the policy development process. Specifically, it provides information on the scale, nature and distribution of the potential benefits and costs for community based forest management. Inclusion of this information in the policy development process provides more rigorous assessment of public investments and improves policy targeting.

Therefore, this study optimised biomass in community based forest management of miombo woodlands with consideration of carbon storage potentials and local livelihoods support function. It explored the state of art in management and growth of miombo woodlands based on literature review as well as examined emerging carbon market potential for CBFM. Based on this information and forest inventory data optimisation model forbiomass management of Tanzanian miombo woodlands under community based forest management was developed. The optimal biomass management by means of mathematical programming techniques has been useful to simultaneously trade-off many competing objectives (Buongiorno *et al*., 2012). In most cases, the variable optimised is resource harvesting efforts and biomass increments distributed over different time horizons, objective function and constraints. The objectives and constraints take into account economic aspect and biological growth patterns of miombo woodlands under community based management intervention.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study was to explore the best ways of optimizing biomass under community based forest management in miombo woodlands while taking into account carbon storage potentials and local livelihood support function in Tanzania.

1.3.2 Specific objectives

The specific objectives of the study were to:

1. Analyze miombo woodlands management and biomass growth for carbon storage potentials inTanzania.
2. Examine land use and cover change in miombo woodlands as influenced by community based forest management and implication to climate change mitigation
3. Examine potential of community based forest management in miombo woodlands of Tanzania from emerging voluntary carbon markets
4. Develop an optimisation model for biomass management of Tanzanian miombo woodlands under climate change mitigation scenario.

1.4 Research Questions

The study strived to answer the following questions:

1. What is the extent of miombo woodlands biomass resource under community based management in Tanzania? (resource inventory)
2. What is the economic value of miombo woodland biomass in terms of carbon storage under given REDD+ initiatives? (CO_2 valuation under given REDD Market)
3. What is the implication of economic values to local livelihoods? (implicit value at local level)

4. How best biomass in community based forest management in miombo woodlands can be optimized to take into account carbon storage and local livelihoods? What would be the implication for this to local livelihoods and climate change mitigation strategy such as REDD+? (Optimisation model)

1.5 ConceptualFramework of the Study

The study applied a dynamic non-linear optimisation model to analyze changes in forest biomass, stand density and utilization under community based forest management. The empirical basis of the optimization model stands out in respect to improved forest biomass for carbon stock and local livelihoods in its entirety. The socio-economic factors and relations affecting miombo woodland management are addressed through incorporation of socio-economic activities such as forest extraction, use of non timber forest products (NTPs) and income from probable voluntary carbon trading. Demand and supply relation for these activities are linked through behavioural, structural and accounting questions. The production, consumption and sale decisions are assumed to be made simultaneously by the households.

This study focused of five key issues as generated from research gap statements (e.g. community based forest management, improved biomass for carbon stock, mitigation of climate change, local livelihoods and optimized biomass management of forest resources). The issue of scale of analysis (plot, household, village and region), time span (static, dynamic, time-recursive) or decision making agents (household, firm, community); interacting units (bio-physical, household preferences, market conditions and the policy/management tools) was incorporated. The illustration to show interactions between forest management, local livelihoods and climate change mitigation linked by arrows have been provided (Figure 1). Since optimisation model is part of bio-economic modelling classified into simulation (what if) or optimisation (what’s best). The study also simulates a system by projecting set of biological and economic variables or parameters into future scenarios to evaluate alternative management strategies.

This optimisation study is designed to find out an optimal biomass management solution of an objective function under certain economic and/or biological constraints. The objective function is maximised when looking at e.g. revenue, profit, harvest, employment, welfare, or minimised when looking at e.g. costs. The constraints can be e.g. limitations on quota, amount of forest harvest, biological stock status, effort distribution, catch dynamics or parameter values (Grafton *et al.,* 2008). In this study, the socio-economic factors and relations affecting miombo woodlands were addressed through incorporation of socio-economic activities such as wood harvesting, Non-timber forest products collection from woodlands and selling carbon credits.

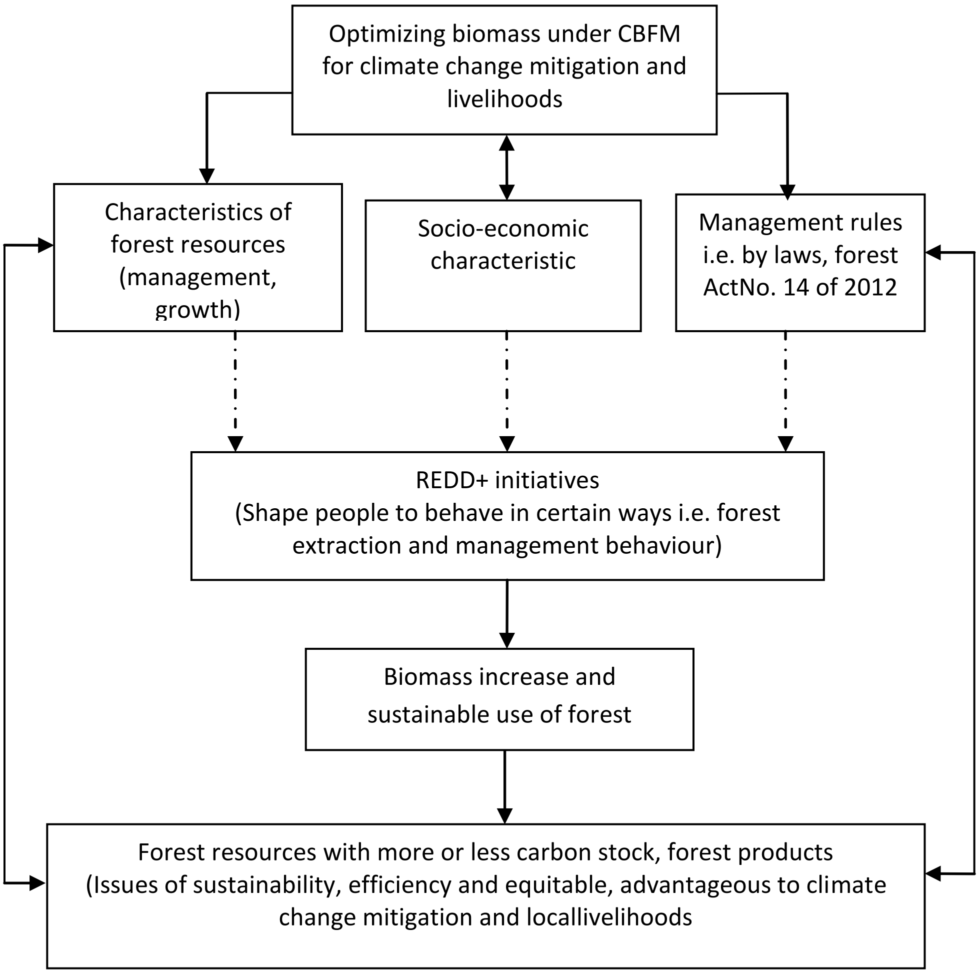


Figure 1: Conceptual framework of the study as modified from FAO (1997).

1.6 Delimitation of the Scope

To preserve clarity and with the view towards practical application, this study focused on forest management in miombo woodlands of Southern Highlands, Tanzania. It was also confined to two districts of Mufindi and Iringa rural districts of Southern Highlands, Iringa region Tanzania. In this study area there is miombo woodlands vegetation under various management options. The main miombo woodlands management options in Tanzania areParticipatory Forest Management (PFM) which includes CBFM and JFM approaches. However, CBFM manage large part of miombo woodlands under village jurisdiction (URT, 1998). Joint Forest Management asecond part of PFM has not been focused much in this study. This study emphasized more on CBFM because of its coverage and ecological and socio-economic importance in miombo woodlands management in Tanzania.

1.7 Key Assumptions

Community Based Forest management is assumed and accounted as a treatment factor. It follows that since CBFM implemented to reduce deforestation and forest degradation in most miombo woodlands under open access regime (Blomley and Iddi, 2009); this study assumes that the rest part of the miombo woodlands are utilized under open access regime represents the situation which could be observed without CBFM practice. Therefore open access forests adjacent to CBFM are assumed and accounted as a control site for baseline information to compare with and without and before and after analysis. This was assuming like a quasi-experimental (e.g. matching-based) research design due to the lack of longitudinal data. Community based forest management outcome parameters measured or estimated from can be compared. Since the comparable pairs of With *vs.* Without CBFM forests are adjoining, the study assume that all other factors affecting growth and performance of trees apart from management through CBFM are kept constant at both sites (With and Without CBFM).

1.8 Limitations of the Study

In this study it was not possible to capture forest biomass and utilization trends over time. However the use of intensive literature review and interview complimented the gaps. Moreover, during questionnaire survey and interviews, respondents relied on memory to recall the past and the present. This practice could jeopardize the accuracy of the information provided. In some instance, respondents failed to provide answers due to memory lapse, or not being aware of the issues pertaining to forest resource management and interventions. Finally, there was a possibility for respondents to deliberately underestimate or overestimate their forest products use in order to impress the researcher; however triangulation helped to normalize the difference.

1.9 Structure of the Thesis

This thesis consists of an extended abstract followed by seven chapters. The abstract summarises briefly the objectives, approach and the main findings of the study. The first chapter cover introduction including background information, problem statement, study objectives, research questions, conceptual framework, delimitation of the scope, key assumptions, and limitations of the study and structure of the thesis. Chapter two provide a general literature review covering theoretical framework of the study, contextual factors promoting CBFM and REDD+ initiatives. Tanzania national REDD+ strategy and socio-economic aspects have been provided. Demand and supply of carbon offsets and accounting issues also have been highlighted. Finally the description of carbon stock quantification and application of optimization techniques in forest management have been provided in this chapter. Chapter three provide detailed description of materials and methods used in data collection and analysis. It includes a description of the application of optimisation model in forest management and decision variables used in optimisation study. Chapter four describe the key characteristics of respondents, focusing on income, demographic and perception of CBFM and forest extraction.Chapter five present a series of papers published as an effort to disseminate key findings and knowledge generated from this study (Paper I, II, III, and IV). Moreover publishable manuscript (Paper V) which is due for submission is also presented in this chapter. Chapter six provide overall synthesis and overall discussion of the findings from the study. Chapter seven highlights key contributions, conclusion, recommendations and areas for further studies.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter reviews the general literature pertinent to the study objectives. It concisely gives an overview of participatory forest management (PFM) in Tanzania and specifically focus on CBFM, local livelihoods, climate change mitigation and sustainable livelihoods framework. It also highlights various issues of carbon financing, marketing and community based forest management as climate change mitigation strategies. The subsequent chapters and papers included also contain concept specific literature review.

2.2 Theoretical Framework of the Study

Participatory Forest Management (PFM) as among the forms of community forest management has received considerable amount of attention in REDD+ debate (Angelsen and Atmadja, 2008; Ostrom, 2009). This management is based on theoretical thinking on how to organize natural resources management in a rational choice theory and institutional analysis approach (Brown and Peskett, 2008). The rational choice theory forms the basis for models such as the ‘tragedy of the commons’. The *tragedy of the commons* describes situation in which multiple individuals, acting independently and solely and rationally consulting their own self-interest. This will ultimately deplete a shared limited resource even when it is clear that it is not in anyone’s long-term interest for this to happen. This theory argues that human societies have an inherently destructive relationship to nature and ultimately overexploit natural resources for their own selfish individual interests. This conception of natural resources has influenced the establishment of forest reserves and protected areas, enclosures and privatization of natural resources.

Institutional analysis approach, however, holds the view that rational individuals can still work together as long as they are organized around common interests and governed by rules. This theory, therefore, underscores the importance of community based forest management in miombo woodlands. Although community forest management has long existed, it gained significant contribution from fields of common property theory, political ecology, ecological anthropology and environmental sociology (Fisher, 2010). According to Wily (2002), CBFM is a generic term to describe resource management approaches that combine three elements: i) recognition of the legitimacy of the values of development and conservation ii) acceptance that development and conservation goals are not necessarily antagonistic iii) commitment to engage local people in environmental management. In many developing countries, community forest management is now mainstream development (Arnold, 2001).

About one quarter of forests is now under the control of local people (Wily, 2002), however unclear socio-economic contribution is a major challenge for emerging REDD+ policy (Peskett *et al*., 2008). CBFM has become an important in management of miombo woodlands of Tanzania. There is increasing interest for CBFM to help mitigate climate change and support local livelihoods (Zahabu, 2008; URT, 2009). Recent studies have shown the great potential of CBFM to reduce deforestation and forest degradation (Lund and Treue, 2008; Vyamana, 2009; Lupala, *et al.,* 2015). Despite of this positive outcome, the management is still challenged from limited tangible incentives provided to local communities (Ngaga *et al.,* 2009; Kajembe *et al.,* 2009; Sangeda *et al.,* 2012).

2.3 Drivers of Deforestation and Forest Degradation

Deforestation and forest degradation as been defined in the previous chapter implies a forest area is cleared, becoming non-forests, i.e. canopy cover falls below threshold level in the range of 10-30% (FAO, 2010; Putz, 2010). Although degradation refers to decreases in density of forest biomass, the how to be measured is yet unclear (Putz, 2010; Hosonuma *et al.,* 2012). Scholars often use the terms interchangeably (Bongers and Tennigkeit, 2010; Chidumayo, 2013), a clear definition is greatly needed (Putz, 2010; Fabiano *et al.,* 2011). These terms are among of the five components included in international policy on reducing emissions (REDD+). The other terms are forest enhancement, sustainable management of forests (SFM) and conservation (UNFCCC, 2009).

Deforestation and forest degradation has been more pronounced in tropical forests (Hosonuma *et al.,* 2012). In Tanzania this has been more significant in miombo woodlands (Lupala *et al.,* 2014). There are various drivers of deforestation and forest degradation in Tanzania as elsewhere (Figure 2). A distinction is commonly made between proximate/direct drivers and underlying/indirect drivers. Proximate drivers are human activities or immediate actions that directly impacts forest cover and loss of carbon stock. For example agricultural expansion, wood extraction and infrastructure expansion. Underlying drivers are complex interactions of fundamental social, economic, political, cultural and technological issues that are often distant from their area of impact. Underlying drivers underpin the proximate causes and either operates at the local level or have an indirect impact from the national or global level (Lusambo, 2009; Chiesa *et al.,* 2009).

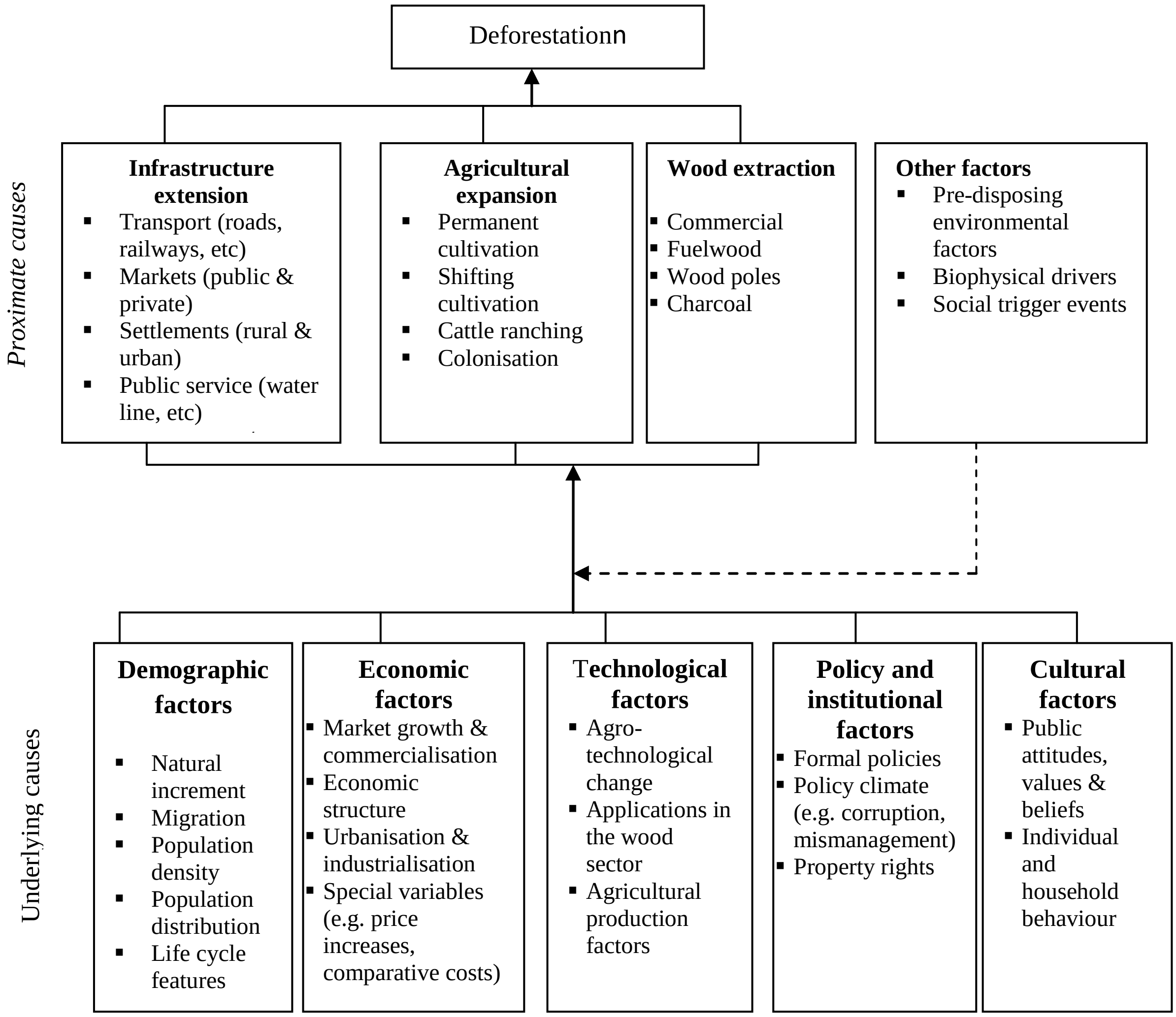


Figure 2: Drivers of deforestation and forest degradation
Source: Lusambo (2009).

Moreover, underlying drivers are related to international markets and commodity prices (Hosonuma *et al.,* 2012). They also include national drivers such as population growth, domestic markets, national policies and governance as well as local circumstances such as local livelihood activities (Lupala, 2009; Hosonuma *et al.,* 2012).

An attempt to quantify the relative importance of drivers contributing to deforestation and forest degradation in Tanzania suggest that fuel wood extraction accounts for the highest percentage (Table 1). Moreover, Malimbwi *et al.* (2001) and Lusambo (2009) also reported that wood fuel consumption is the main cause of deforestation in Tanzania. It is also responsible for degradation of about 25% of closed woodlands and deforestation ranging from 20% to 51% of closed and open woodlands respectively (Fabiano *et al.*, 2011). Lusambo (2009) found that forests in Tanzania are threatened by wood fuel extraction, rapidly expanding population, commercial felling of timber and expanding agriculture.

Table 1: Relative importance of factors contributing to deforestation in Tanzania

Activity	Hectares/ annum	Percentage
1. Fuelwood extraction	575000	55.4
2. Land clearing for agriculture	400000	38.6
3. Tobacco curing	40000	3.8
4. Commercial logging	17 650	1.7
5. Uncontrolled fires and others	4 335	0.5
Total area deforested	1 036 985	100
Less		
6. Natural regeneration (50%)	518 493	50
7. Reforestation	3 500	0.3
Estimated net deforestation	514 992	49.7

Source: Kulindwa and Shechambo (1995).

Hosonuma *et al.* (2012) also supports the idea that wood fuel is a significant cause of deforestation. Wood fuel is the major forest product and the main source of energy in Tanzania accounting for 91% of total energy and about 95% of total wood consumed in the country (Lusambo, 2009).

Deforestation and forest degradation occurs in both forest reserves and non reserved forests (Zahabu, 2008). However, compared among different vegetation types of

Tanzania, miombo woodlands pose more significant challenge (Bongers and Tennigkeit, 2010). Miombo woodlands are severely under threat of deforestation and forest degradation (Campbell *et al.,* 2007). Conversion into agricultural lands lead to fragmentation and isolation; legal and illegal logging and extensive extraction for fuel wood and wild fires have been a continuing challenge in the woodlands (Miles *et al.*, 2009; Fisher *et al.*, 2011).

Interestingly, a recent analysis of forest vegetation cover change in Tanzania as a result of PFM management intervention has reported a declining rate of deforestation in most forest reserves (Fabiano *et al.,* 2011). This observation is in line with earlier studies that documented positive ecological effects from PFM i.e. Wily, (1999) for Tanzania, Poffenberger (2006) for Southeast Asia, Nittler and Tschinkel (2005) for Guatemala. According to Fabiano *et al.* (2011) the rate of deforestation in Tanzanian forest reserves were 1.3% year^{-1} in 1990 to 2000 and decreased to 0.6% year^{-1} in 2000 to 2007.

2.4 Sustainability of Forests and Miombo Woodlands in Tanzania

2.4.1 Legal framework for sustainable forest management

The national forest policy together with the legal frameworks guide decision-making and constitute the basis for sustainable forest management (Dewees *et al*., 2010; FAO, 2010). In pursuit of sustainable forest management (SFM), Tanzanian forest policy of 1998 and forest Act No.14 of 2002 recognizes and advocates PFM as the mainstream forest management approach. The fundamental hypothesis of PFM are found in literature (e.g. Adhikari, 2005; Agrawal and Gibson, 1999) includes (a) greater local control over forest management will results in more heather (vigorously growing) forest and woodlands due to better protection and ecologically sustainable utilization (b) greater local control increases local community benefits associated with forest and forest management.

Despite of the plausible hypothesis behind it, yet still it is unclear with regard to the extent at which the management and growth of forests and livelihoods objectives have been realized in Tanzania (Ngaga *et al*., 2009; Blomley and Iddi, 2009).

The common agreed characteristics embedded within community forest management is that local people are capable of undertaking useful role in forest management and have legitimate right to participate (Blomley, 2013; Ostrom, 2009). However, what drives co-management? How and why have these regimes emerged? Why is it important in Tanzanian forest management? Have been extensively reviewed (e.g. Kajembe *et al.*, 2009; Ngaga *et al.*, 2009; Vyamana, 2009). Participatory forest management in Tanzania has two pillars, namely Joint Forest Management (JFM) and Community Based Forest Management (CBFM) (Table 2).

Table 2: Legal frameworks for forest management practiced in Tanzania

Legal description	**Role of Community/Individual in Management**	**Common Name**
Village Land Forest Reserve (VLFR) managed by the entire community	Owner and manager	Community Based Forest Management (CBFM)
Community Forest Reserves (CFR) managed by a particular designated group in the community, authorized by the village council	Owner and manager	Community Based Forest management (CBFM)
Private Forests (PF) managed by individual designated households.	Owner and manager	Private Forest Management
Joint Management Agreement (JMA) where management responsibility is shared between either central/ local government and forest adjacent communities or transferred completely.	Co-manager Designated Manager	Joint Forest Management (JFM) Joint Forest management (although this form is rarely practiced).

Source: Blomley and Iddi (2009).

CBFM is highly practiced in miombo woodlands which face high rate of deforestation (Zahabu, 2008, MNRT, 2008). These forest lands were mainly previously known as open access forests, i.e. access was free and unregulated, possibly because rights were only nominal and unenforced (Adhikari, 2005). Joint Forest Management (JFM), have been implemented on high mountain forests with high level of biodiversity and catchment values (Blomley and Iddi, 2009).

The community based forest management frameworks took advantage of existing local government institution. Local government structures in Tanzania provide local communities with legal forum through elected village councils and village assemblies (Blomley and Iddi, 2009). These include the Land Act No. 4 (1999) and the Village Land Act No.5 (1999), which all provides legal rights and provisions at the grass-root level (Blomley and Iddi, 2009). PFM has been framed within this framework and is expected have more effective contribution to sustainable forest management and local livelihood improvement (Sunderlin *et al.,* 2005; Agrawal and Angelsen, 2010).

In this study, community based forest management is defined as '*de-jure*' government approved forms of forest management by local communities with the core objectives of providing local community with social and economic benefits while promoting sustainable forest management (Agrawal, 2007). Moreover, there must be some degree of control and decision-making power vested in the community by the government (Ostrom, 2009). This management approach is considered to produce increasing benefits, make use of local knowledge, encourage voluntary compliance, and trigger innovation and contribute to sustainable forestry comprising economic, social and ecological benefits (Poffenberger, 2006). In addition, it is hoped that devolving management rights and responsibilities to local people will avoid 'tragedy of the commons' and encourage local people to actively manage the forest resulting in both ecological and economic benefits (Agrawal and Angelsen, 2010).

2.4.2 Climate change mitigation and sustainable forest management

The international policy approach and positive incentive which aims to reduce emissions from deforestation and forest degradation in developing countries by preserving the existing natural forests is termed as REDD+ (UN-REDD, 2009). The central idea of REDD+ is to develop the multilevel system of payments for ecosystem services (PES) (Peskett *et al.,* 2008; Laurence, 2009). In other words, REDD+ provides performance-based financial compensation to the forest owners to protect forest, use less forest land and favour the forest management (Angelsen *et al.,* 2009). REDD+ is targeted to address a significant portion of greenhouse gas emissions (Peskett *et al.,* 2008). It is the mitigation option with the largest and most immediate impact on stabilizing and enhancing the global carbon stock per ha per year than a forestation and reforestation (A/R) schemes (IPCC, 2007). The focus of REDD+ includes environmental objectives, but they often claim to be alleviating poverty as well (Laurence, 2009).

REDD+ initiatives are not included in Kyoto Protocol (KP). The main reasons for the exclusion were leakage risk, non permanence, baseline, monitoring and measurement uncertainties and challenges in demonstration of both financial and environmental additionality (Angelsen *et al.,* 2009). There was also a key question in the international debate concerned with geographical scale of REDD+ (Peskett *et al.,* 2008). This includes accounting of total emission reductions and hence the base for the credit payments (Laurence, 2009). There are three proposed levels: national, supporting programmes and activities implemented via government; sub national, supporting individual projects; and hybrid or ‘nested’ approach combining the national and sub national approach (Angelsen *et al.,* 2009).

Most of the REDD+ carbon credits are being sold through carbon forest projects operating in voluntary markets (Laurence, 2009). These projects often include combination of reforestation and forest conservation activities (Peskett *et al.,* 2008). Due to agreement on the scope of the activities under the Bali Action Plan, REDD has evolved to REDD+, where “plus” represents conservation, sustainable forest management and enhancement of forest carbon stock (Decision 2/CP.13) (UNFCCC, 2008). The sustainability and institutionalization of REDD+ activities under the UNFCCC are still uncertain (Laurence, 2009).

However, the promise and the potential of REDD+ are to serve as a link between climate change mitigation, forest conservation and poverty alleviation (Angelsen, 2008; Laurence, 2009). The initiative is designed to encourage developing countries with tropical forests to undertake measures that will minimize the rate of deforestation and forest degradation (Angelsen, 2008; Karsenty, 2008). Despite of this, the structure on how REDD+ will be designed and financed as well as its implications to local livelihoods and sustainable forest management is yet unclear (Schmidt, 2009).

REDD+ is still in its infancy in many developing countries and it is not yet established how these countries and their local communities will participate, how they will be affected and what options they will offer in the design and implementation of REDD+ (Schmidt, 2009). The promising incentives from REDD+ aims at changing economic incentives and discourses to minimize deforestation and forest degradation activities.

However, the implication of REDD+ to the local livelihoods in developing countries is yet unclear (Brown and Peskett, 2008).

2.4.3 Sustainable livelihoods framework

Sustainable livelihood is taken as an integrating concept for paradigm of development process (DFID, 1999). A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living (Carney, 1998; DFID, 1999). A livelihood is sustainable when it can cope with and recover from stresses and shocks maintain or enhance its capabilities and assets, while not undermining the natural resource base. The widely appreciated feature of livelihoods thinking and approach is that it directs attention to a holistic approach, to the multiple forces and influences on people‟s livelihoods, to the assets and access to assets, and to the options people possess in practice to pursue alternative activities (Fisher, 2010). Since the introduction of the livelihood concept, it has been re-defined and modified by different scholars and development agents to adapt to their own needs and circumstances. The department for international development (DFID) of the UK (DFID, 1999) developed a widely used framework for livelihood analysis (Figure 3).

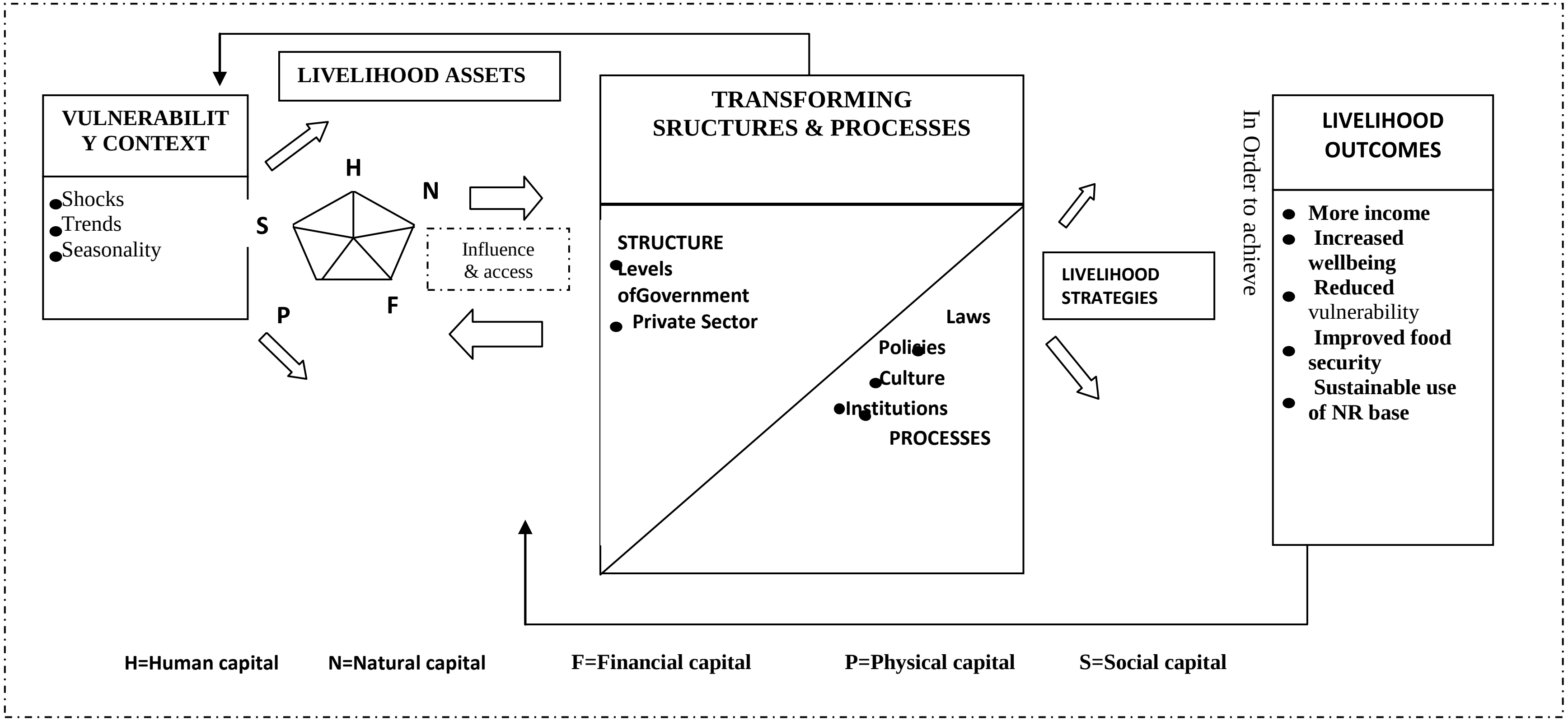


Figure 3: Sustainable Livelihoods Framework

Source: DFID (1999).

The vulnerability context refers to those aspects of the external environment that influence livelihoods and over which people have limited or no control (DFID, 1999). Five types of livelihood assets (capitals) are recognized: natural, physical, human, financial, and social capital.Natural capital refers to environmental resources such as land, water, and biological resources whereas physical capital stands for those assets created by production processes such as buildings, roads, farm equipment, tools and irrigation canals (Ellis, 2000). Human capital refers to labor together with its education level, skill and health (Carney, 1998). Financial capital measures theavailability of cash or the equivalent that enables people to adopt different livelihood strategies (DFID, 1999). It can be in the form of savings, loans or other transfers. Social capital refers to the social resources upon which people draw in (e.g. social networks, membership in formal and informal groups, and participation in relationships of trust, reciprocity and exchanges) (DFID, 1999). The transforming structures and processes include the institutions, policies, and organizations that determine access to assets, returns to livelihoods strategies, and terms of exchange between different types of capital (DFID, 1999). Ellis (2000) considered them as critical mediating factors that inhibit or facilitate households‟‟ exercise of capabilities and choices.The interplay of the vulnerability context, livelihoods assets, institutions and organizations influences the adoption of particular livelihood strategies and livelihood outcomes.

2.4.4 The Tanzanian national REDD+ strategies

Tanzania’s government has already made significant progress in developing a national REDD programme and strategy framework (URT, 2009). The framework emphasizes the involvement of the local communities in the design and implementation of reducing emission from deforestation and forest degradation activities. It also recommends that the REDD+ strategy need to be pro-poor (URT, 2009). In Tanzania there are various REDD related pilot projects, innovations and technologies already that could help to increase carbon sinks (URT, 2009).

For example, it is reported that there are 382 village forest reserves (VFRs) with a total area of 2.06 million hectares (ha) in 1202 villages under CFM (MNRT, 2008). This land provides a significant carbon sink that can be designated for REDD+ projects in the country. These forested lands are very important as they stimulate and diversify local economy, stimulate new enterprises through tourism, improve living standards and create employment for the local communities. They also provide environmental education for visitors and locals while enhancing intercultural understanding, encourage the development of culture, crafts and the arts and increase the education level of the visitors and locals.

Numerous challenges that can affect REDD+ effectiveness to deliver sustainable forest management and local livelihoods improvement. The challenges include: - What is the present nature and extent of the forests and miombo woodland biomass resource? What is the economic value of forests and woodland biomass in terms of carbon storage and sequestration under given REDD+ initiatives? What is the implication of these economic values to local livelihoods? Are there possibilities to optimize carbon storage and local livelihoods in miombo woodlands of Tanzania for REDD+ initiatives? How changes in biomass in the right of REDD+ initiative can play a catalytic role in maintaining, enhancing community forest management and local livelihoods?

These challenges are not withstanding, as according to Dewees *et al.* (2010) the successful management of African miombo woodlands is important for three reasons; (i) they sequester enormous amounts of carbon (ii) they support livelihoods of millions of people and provide a renewable source of energy, i.e. fuel wood and charcoal; and (iii) their successful management would contribute to poverty alleviation by supporting and strengthening local livelihoods strategies. In times of stress the forests serve as an insurance against famine by offering a source of wild foods and fruits and other useful products (Paavola, 2008; Dewees *et al.*, 2010; Lupala, 2009). Against this background, REDD+ could combine carbon sequestration with SFM, poverty reduction if it is designed so as not to unduly restrict current forest uses for livelihood purposes.

2.5 Carbon Stock Markets, Standards and Trading Portfolios

2.5.1 Existing carbon offset markets and standards

Since the signing of the Kyoto Protocol in 1997, several carbon markets have emerged, both regulatory and voluntary (Capoor *et al.*, 2008). The regulatory markets are related to activities that are taking place under international negotiations through the United Nations Framework Convention on Climate Change (UNFCCC), whilst voluntary markets are evolving on a voluntary basis, mainly driven by the private sector and consumer interest (HC, 2007). The voluntary market generate carbon credits, whilst at the same time improving local livelihoods and enhancing the environmental services provided by forests such as biodiversity and watershed (WWF, 2008). The voluntary carbon market (VCM) supports different kinds of activities in the forestry sector, including protection of forests, improving forest management, planting trees on non-forest land, and the rehabilitation of degraded forests and forest areas.

Individuals, business, NGOs or governments, coming from non-Kyoto compliant countries or from unregulated sectors, can offset their emissions through this market (WWF, 2008). Voluntary carbon markets pertain to trading in all carbon offsets that are not required by regulation. Unlike markets, such as the European Union Emission

Trading Scheme, that exists to support compliance with legislated carbon emissions caps, voluntary markets represent voluntary attempts by individuals and organizations to reduce their carbon emissions (Bayon *et al.,* 2007).

A cap and trade system distributes allowances that must be used by entities under the cap to cover their emissions. The credit system is where credits are earned by reducing emissions below a baseline (WWF, 2008). If a participant in the market can reduce emissions below its cap, it can bank (carry forward) or sell its allowances (Capoor *et al.,* 2008). By permitting trade, the system encourages the most efficient operators to reduce emissions and results in a lower- cost abatement strategy than would occur under fixed individual targets. A credit system operates on a voluntary basis (WWF, 2008), which operates in parallel to the regulated markets and it has developed independently of government targets and policies.

In either case, buyers seek guarantees that the credits they purchase actually reduce net carbon emissions and do so without negative impacts on biodiversity and local livelihoods (WWF, 2008). There are more than a dozen standards and certification systems that have been developed to provide these assurances (Hamilton *et al.,* 2010). Only some of these certify REDD+ projects and address persistent questions about additionality, leakage and permanence of REDD+, as well as looking at impacts on local people and the environment. These standards differ in focus, from being exclusively interested in potential social benefits of the projects to the ones closely specialized in particular sectors like energy efficiency, agriculture or forestry.

The leading standard is the Voluntary Carbon Standard (VCS), used by more than third of all credits traded in the voluntary markets in 2009 (Hamilton *et al.*, 2010).

The VCS focuses on the integrity of emissions reductions, including an independent risk analysis and required contributions to a pooled buffer. It has partnered with 3 registries to tract its verified Voluntary Carbon Units (VCU). Many REDD+ projects intended to certify their credits to the VCS (Ecosecurities, 2010). The other leading standards for REDD+ projects were developed by the Climate, Community and Biodiversity Alliance (Richards and Panfil, 2010). The CCBA maintains a registry of projects that have been certified to its standards, but does not issue verified emissions credits (Richards and Panfil, 2010).

The CCB standards were originally designed to help differentiate high-quality projects that respect the rights of and generate benefits for local people as well as conserving biodiversity. However, CCB certification has become essential for both market access and credibility (Point Carbon, 2007). For example, many REDD+ project proponents regardless of whether they plan to sell credits also aim to meet CCB standards (Madeira *et al.,* 2010).

In addition, Plan Vivo (PV) was developed as a set of standards, processes and tools used to build up official PES projects implemented by local community members on their own land or on the land they have right to use particularly in developing countries (HC, 2007). Project activities are connected with forestry management through reforestation, agroforestry, avoided deforestation and forest degradation. The main focus of this standard is the promotion of sustainable development and improving livelihood and ecosystem (WWF, 2008). However, efficient emissions trading system requires comprehensive data on green house gas emissions and sequestration (Point Carbon, 2007). This may be a problem for some developing countries which do not have the necessary skills and infrastructure (van Kooten *et al.*, 2007). There are several other standards designed to be stacked on carbon accounting standards, such as Social Carbon, although these have much more limited coverage (Point Carbon, 2007).

2.5.2 Demand and supply in carbon market and carbon offsets

The emergence of voluntary carbon markets in many parts of the world have been driven primarily by the expanding demand for reduced carbon emissions from deforestation and forest degradation as a means to mitigate climate change (Peskett *et al.,* 2008; Bayon *et al.,* 2007). Carbon offsets sold in the voluntary markets (Voluntary Emissions Reductions) tend to be cheaper than those sold in the compliant markets (HC, 2007). The voluntary carbon offset market is currently the only sales outlet for carbon credits generated by REDD+ projects. This market includes a wide range of exchanges, brokers and buyers making direct purchases. Hamilton *et al.* (2010) recorded 2846 ktCO_2e in REDD+ credits traded in 2009, up sharply from 730 ktCO_2e in 2008.

While there has been an up and down year for global economy, carbon market has been on a continuous upward trajectory (Figure 4). The market for forest carbon credits has experienced steady increase over the past ten years despite the economic recession (Peters-Stanley, 2012). This is a clear indication of the business community's interest to take action on climate change both in the absence of and as a complement to regulation on emissions. Buyers are often motivated by corporate social responsibility or desire to position themselves for expected future compliance markets.

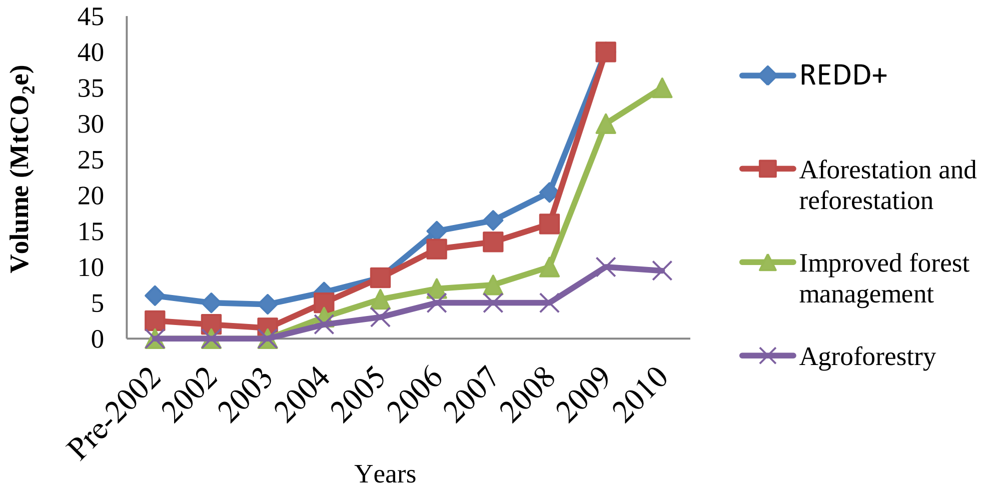


Figure 4: Trend of voluntary carbon market from pre-2002 to 2010

Source: Peters-Stanley (2012)

These markets have shown impressive growth in recent years (Peters-Stanley, 2012). They grew at 300 per cent by volume between 2005 and 2006 and are now valued at more than $90 million (Hamilton *et al.*, 2007). REDD+ financing, improved forest management and afforestation projects moved rapidly to a position of significance. In project terms, REDD+ projects accounted for 62 or 8.5% of the 723 forest project commitments identified by OECD in 2010 (Peters-Stanley, 2012). The average price for various carbon offset projects from 2009 to 2010 has been significant (Table 3).

Table 3: The average price for various carbon offset projects from between 2009 to 2010 markets

Type of project	2009 average price (USD)	2010 average price (USD)
Solar	34	16
Biomass	12	10
Wind	9	9
Improved forest management	7	6
Agroforestry	5	10
Afforestation & reforestation	5	9
Avoided deforestation	3	5

Source: Peters-Stanley (2012)

A recent market survey found that many buyers were willing to pay a price premium for projects with both VCS and CCB certification (Ecosecurities, 2010). In overall, indicative average price for carbon storage due to improved forest management in 2010 was USD 6/tCO_2e, in 2009 increased to USD 7/tCO2e in 2010. The trend is based on the increasing carbon credit markets, standards and certifications. Therefore, by increasing value of forest carbon and rewarding those most responsible for the conservation efforts, namely forest dependant people, REDD+ has the potential to generate important improvement in the welfare of millions poorest segments of the society.

2.6 Carbon Stock and Emission Accounting in Forest Management

2.6.1 Carbon accounting current status and challenges

Forest carbon accounting often refers to accounting of carbon dioxide equivalent (CO2e), a metric which allows standardisation of the six major GHGs based on their global warming potential (IPCC, 2003). Carbon accounting is the practice of making scientifically robust and verifiable measurements of GHG emissions (Ngo *et al.,* 2013). This accounting for forest carbon is a more recent addition to forest inventories. It follows the growing need to quantify the stocks, sources and sinks of carbon and other GHGs in the context of anthropogenic impacts on the global climate. Therefore, good accounting practice promotes better understanding, legitimacy and trust in the accounting system, which is critical for both political and public acceptance.

However, there are several key gaps and limitations in the existing literature on carbon accounting that prevents the precise evaluation of these mitigation strategies (Kauffman *et al.,* 2009). These include inadequacies in carbon pool quantification, broad categorization of land use types and conversion histories, inadequate measurement and/or reporting of critical site-specific factors, and the inevitable uncertainty associated with future predictions (Kauffman *et al.*, 2009; Omeja *et al.*, 2012). These inaccuracies limit the efficacy of global and national policies aimed at reducing atmospheric carbon levels through forest mitigation strategies (Ngo *et al.,* 2013). Without reliable input data to support site-specific carbon sequestration potential, resources may be invested in sequestration or offset projects that are either (a) unlikely to achieve their stated objectives or (b) sub-optimal compared to other land use options for carbon offsets (Omeja *et al.,* 2012).

2.6.2 Quantification of forest carbon stocks

Forest carbon stocks are typically divided into five pools: above ground biomass (AGB), below ground biomass (BGB), soil organic carbon (SOC), coarse woody debris (CWD), and litter (Woodall *et al.,* 2013). The proportions of carbon stock in each pool are affected by numerous factors including forest management and age (Kauffman *et al.*, 2009). This is highly relevant because different pools exhibit different rates of sequestration and storage capacity following natural succession or management practices (Omeja *et al.,* 2012). The main challenges with regards to quantification of forest carbon stocks estimates described in Figure 5.

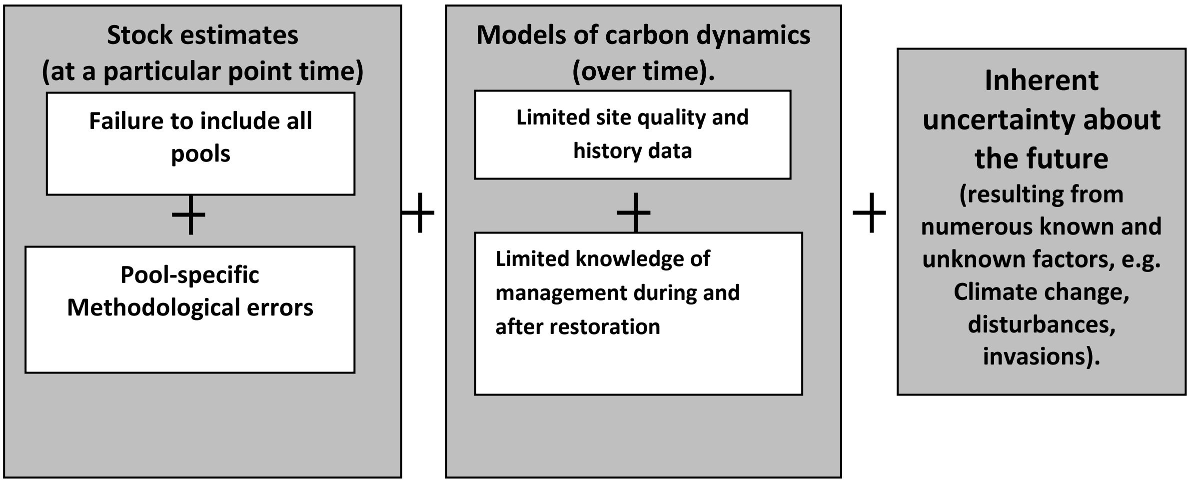


Figure 5: Sources of uncertainties in forest carbon accounting

Source: Omeja *et al.*(2012)

This includes the failure to measure all carbon pools; however, one of the large sources of uncertainty in all estimates of carbon stocks in tropical forests is the lack of standard models for converting tree measurements to aboveground biomass estimates (Gibbs *et al.*, 2007; FAO, 2009). The forest biomass measurements are usually carried out through standard inventory techniques using ground based plots and converted to aboveground biomass using either biomass expansion factors or allometric regression equations (Gibbs *et al.*, 2007; Mugasha, 2014).

Furthermore, a compilation of existing roots biomass data also generate a significant regression equation that can be used to predict root biomass based on aboveground biomass only (Terrestrial Carbon Group, 2010; IPCC, 2007). Methods for measuring coarse dead wood have been tested in many forest types (Hosonuma *et al.*, 2012), but the methods could be improved if a non-destructive tool for measuring the density of dead wood was developed (Gibbs *et al.,* 2007). Models involving only trunk diameters are usually preferred for tropical natural forests (Gibbs, *et al.,* 2007). However, the future measurements of carbon storage in forests may rely more on remote sensing data, and new remote data collection technologies are in development (FAO, 2009).

2.6.3 Accounting for emission reduction

Accounting for emission reductions requires an understanding of a number of supplementary principles. These principles include the complexities of baseline establishment, demonstration of additionality, issues of leakage, and the permanence of emissions reductions. In order to set emission reduction targets, a baseline scenario must be developed (IPCC, 2003). The baseline is also called a counterfactual; this baseline scenario estimates what would have happened in the absence of a policy or project. It is required so that the mitigation impact of a project or policy can be quantified.

In the forestry sector, the baseline is particularly important in attempts to reduce emissions from deforestation and degradation. However, challenged by both technical and political considerations (Bond *et al*., 2009).

For a project to be additional, it must be proven that emission reductions would not have occurred in the absence of a project. This is an important principle when emissions reductions at a project location are used to offset GHG emissions at another location. Leakage is a process by which emissions are reduced in one area but are also impacted outside of the area in question. Although positive leakage is a possibility, concern is directed to negative leakage, where emissions are merely shifted to another geographical area and fewer, or no, actual reductions are generated by the project activities (Woodall *et al.,* 2013). Leakage can be sub-divided into a number of categories including slippage, activity shifting, outsourcing, market effects and life-cycle emission shifting and can be one-time or recurrent (Ngo *et al.,* 2013). Adequate assessments of leakage are crucial and identification requires the main drivers of the project baseline to be properly addressed (IPCC, 2003).

Permanence refers to the persistence of emission reductions over time. Unlike other sectors, such as industry, energy, waste management and transport, there is a risk that forest carbon sinks, having delivered emissions reductions, may deteriorate or be depleted over the long term (IPCC, 2007). This could be a result of natural disturbances including fire, pests and disease, or anthropogenic disturbances such as poor management and political instability leading to land-use change. Forestry emission reductions are, therefore, unlike those from other sectors in their certainty of delivery.

2.7 Optimization Modelling and Its Application in Forest Management

2.7.1 The concept of optimizationmodelling

The concept of optimizationmodelling developed since the end of the 1950's from the works of Gordon and Schaefer (Grafton *et al.,* 2008). Recently, there is a growing interest in using optimization models as a tool for policy analysis to better understand pathways of development and to assess the impact of alternative policies on the natural resource base and human welfare (Hennigar *et al.,* 2008). One of the potential benefits of these models is that one can get a better and more comprehensive indication of the feedback effects between human activity and natural resources (Buongiorno *et al.*, 2012).

Optimization modelis a kind of bio-economic modelwhich can be classified into two categories, simulation (what if) or optimization (what's best). Simulation models strive to simulate a system by projecting set of biological and economic variables or parameters into future scenarios to evaluate alternative management strategies. Optimization models are designed to find an optimal solution of an objective function under certain economic and/or biological constraints. The objective function is to be maximized when looking at e.g. revenue, profit, harvest, employment, welfare, or minimized when looking at e.g. costs. The constraints can be e.g. limitations on quota, days at sea, biological stock status, effort distribution, catch dynamics or parameter values (Grafton *et al.*, 2008).

Normally constraints are constructed by using inequalities instead of equalities. In that sense the restrictions define a flexible area, and a solution is found within this area, given a pre-defined objective. Simulation models rely on the same set of boundaries and parameter values, but these can be seen as a set of rules that determine the dynamic consequences of renewable resources (Buongiorno *et al.*, 2012). Bio-economic models are developed to capture either short-run (i.e. population dynamics) or long-run structural behaviour (i.e. investment or entry/exit decisions) on a temporal or spatial scale.

The development of bio-economic models in developing countries has been slow because of the complexity of socio-economic as well as biophysical conditions (Barbier and Bergeron, 2001; Buongiorno *et al.,* 2012). A dynamic or evolutionary perspective is required in order to handle inter-temporal issues. However, the integrated frameworks of bio-economic models capture biophysical processes evolution along with rational human management responses (Buongiorno *et al.,* 2012).

2.7.2 Application of optimization models in forest management

Theoretically, optimization models draws from Mathematic theory of optimisation. According to this theory, nature inherently seeks optimal solutions. There are numerous computationally hard problems arising in real world applications and for those problems, the exact optimal solution is not computable and therefore approximate solutions are computed with various kinds of heuristics. These heuristic works to solve large problems lack solid theoretical analysis except Karmakar's algorithm or linear programming (Du *et al.,* 2013).

Optimisation models of different kinds have traditionally been used in forest management and forest product industry (Grafton *et al.,* 2008; Keles, 2010; Buongiorno *et al.,* 2012; Sangeda, 2013). Most of these models are designed following specific structures of formal mathematical programming models such as linear programming, dynamic programming and simulation (Buongiorno *et al.,* 2012).

Despite the apparent potential of these mathematical models to optimize wood processing and forest management activities, their application to real-world problems has been limited (Sadeghi *et al.,* 2009). This is partly because they are often regarded as too mathematical and incomprehensible to be successfully applied. End-user optimisation is becoming more widespread in a number of manufacturing enterprises. With the advent of better computer technology and increased numbers of user-friendly software, end-user optimisation models have become more popular. One of the main instruments in bringing optimisation to end-users is the spreadsheet model such as solvers add in (Buongiorno *et al.,* 2012; Sangeda, 2013).

The capability of solver spreadsheet software enables the decision maker to quickly evaluate many different scenarios. This feature provides a quasi-optimisation capability in which the decision maker can systematically evaluate a set of decision alternatives, modify one or more parameters, and evaluate their impacts (Buongiorno *et al.,* 2012). This interactive and iterative feature can be performed in a number of times until an acceptable set of decision variables has been reached. However, the use and application of optimisation modelling has been in the form of academic pursuits rather than being toiled towards practical application (Grafton *et al.,* 2008). Even with limited scopes, optimisation models in management of Tanzanian miombo woodlands could be more useful for the concern of multiple objectives. According to Keles (2010), optimisation analysis assumes a great significance in the context of developing country like Tanzania. This is due to the rapidly growing population, marginalized agriculture, fragile ecosystems such as miombo woodlands and high rate of deforestation and forest degradation. Optimisation model nests essential biophysical process within economic behavioural models and the constrained optimisation perspective allows evaluating how technological and policy changes would affect economic welfare, sustainability and forest conditions over time (Hennigar *et al.,* 2008; Sangeda, 2013).

The idea of using models in problem solving and decision analysis is not new, models allow us to gain insight and understanding about the object or decision problem under investigation (Barbier and Bergeron, 2001). Optimization models nests essential biophysical processes within economic behavioural models and the constrained optimization perspective allows evaluating how technological and policy changes would affect economic welfare, sustainability and forest conditions over time (Stein and Holden, 2005). These models are typically applied programming models that may have a basis in simpler theoretical dynamics or static models (Buongiorno *et al.,* 2012). In developed countries such models have mostly focused on environmental pollution, while in developing countries they have focused on land degradation and forest conservation (Hennigar *et al.,* 2008).

In this study, a dynamic non-linear optimization model was used to capture the entire system behaviour affecting deforestation and forest degradation, approximated through changes in forest biomass and stand density and utilization. The empirical basis of the developed model in this study stands out in respect with endogenization and addressing forest biomass for carbon stock and local livelihoods in its entirety. The socio-economic factors and relations affecting miombo woodland management are addressed through incorporation of socio-economic activities such as wood harvesting, livestock keeping and cultivation. Demand and supply relation for these activities are linked through behavioural, structural and accounting questions. The production, consumption and sale decisions are assumed to be made simultaneously by the households.

Moreover, optimization model provide better understanding of the evolution in patterns of land use and human welfare (pathways to sustainable forest management and enhancement of carbon stock and sequestration). Because the model shows the changes which take place due to population growth, land degradation, technological and institutional changes as well as exogenous shocks. It may also be used to predict future changes in land use under different policy scenarios or other alternative assumptions about changes in exogenous condition. Bio-economic models may also serve as a tool for interdisciplinary analysis (Barbier and Bergeron, 2001), both for identification of knowledge gaps and assess the sensitivity of outcomes (impacts) to alternative assumptions about parameter values and structural relations (e.g. market characteristics). In the present study, bio-economic analysis projected the present forest stock in terms of biomass and evaluates alternative management effects; both biophysical data which describe operational stands of interest and socio-economic data which describe management and resource use at household level were used.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter describe the location of study area and its characteristics, methods of socio-economic and ecological data collection and analysis as well as consideration of ethical issues. It further provides the structure of the optimization mode, its decision variables and model scenarios.

3.2 Description of the Study Area

This study was carried out in Iringa region in Southern Highlands of Tanzania, located between 6^{o}, 55’ and 10^{o}, 30’ south of Equator and between longitudes 33^{o} 45’ and 36^{o}55’ east of Greenwich. Ecologically, the study area represents miombo woodlands dominated by genera *Brachystegia*, *Julbernardia*, and *Isoberlinia* species in a relatively flat area at 1200–1500 m.a.s.l. The woodlands are Mandumburu (Tambalang’ombe village), Kingegenyanyembe (Kingegenyanyembe village), Kidundakiyave (Kihwele village) and Gangalamtumba (Mfyome village) (Figure 6 and Table 4).

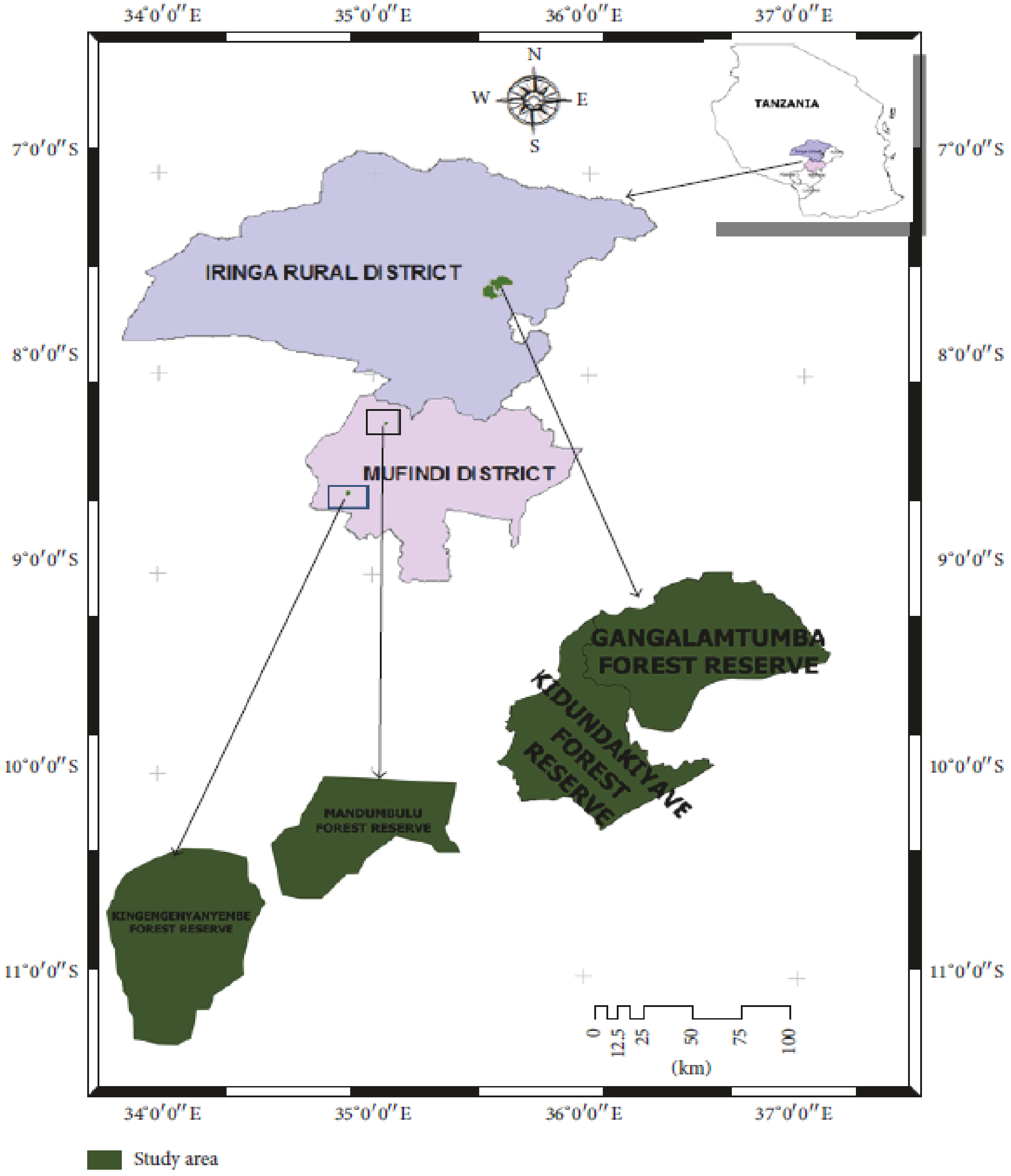


Figure 6: Geographical location of study districts and respective forests of Southern Highlands of Tanzania.

Table 4: Location and climatic characteristics of miombo woodlands, village and household size

District	Name of miombo woodlands	Village name and household size	Location	Altitude (m)	Dominant soil type	Mean temp (^{o}C)	Mean rain (mm)
Iringa rural	Gangalamtumba (6,065 ha)	Mfyome (648)	7^{o}35’S	850-1,300	Sandy clay loam soil	19.8	617
	Kidundakiyave (4904 ha)	Kihwele (479)	7^{o}59’S 35^{o}79’E	850-1,300	Clay alluvial soils	21.5	600
Mufindi	Mandumburu (450 ha)	Tambalang’Ombe(462)	8^{o}43’S	1180-1500	Sandy loam soils	24.6^{o}C	630
	Kingegenyanyembe (459.6 ha)	Kingegenyanyembe(606)	8^{o}.00’S 35^{o} 15’E	1600-1800	Sand clay soils	22.6^{o}C	584

Source: Village governments’ records (2013)

The selected study areas were Mufindi District situated at about 80 km from Iringa Municipality along Dar es Salaam-Mbeya to Zambia main road and Iringa Rural District situated about 30 km from Iringa Municipality. Community based forest management (CBFM) started in 2003 with technical support from Danish International Development, (DANIDA) (Lund *et al.,* 2009). Sustainable forest extraction within community based forest management is allowed (URT, 1998). As in other parts of the country, agriculture is the major occupation of the local community while other economic activities include charcoal production, livestock keeping, petty business and casual employment.

The main land use systems in Iringa Region include farming, forests, livestock keeping, agroforestry and settlements. Much of the land is under agriculture because of its suitability for cultivation. In general there has been substantial conversion of natural forests and other habitat to agriculture. Both Iringa Rural and Mufindi districts, between 70 to 80 percent of the original forest cover was removed to make way for agricultural land uses (URT, 2007). The major economic activities in the region is agriculture through subsistence farming and farmers often own scattered pieces of lands usually less than 5 acres.

Maize (*Zea mays* L.) is the most important crop in the village, accounting for about 85% of all the crops cultivated. Markets for agricultural outputs are heavily influence by distance to town centres, road, processing industries and of course general prosperity levels of the community. The households are mainly producers and consumers of major forest and agricultural products. Labour is mainly provided by the household members and farm labour peaks occur during planting and harvesting seasons. The climate of the area is bimodal with rain season from October to May and dry season from June to September. The mean annual rainfall is 500-600 mm and the mean annual temperature is

21°C (Figure 7). Most of the area is dominated by clay soils with high swelling and shrinkage characteristics. These soils in miombo woodlands are nutrient-poor and the natural vegetation is dry miombo woodlands (Frost, 1996).

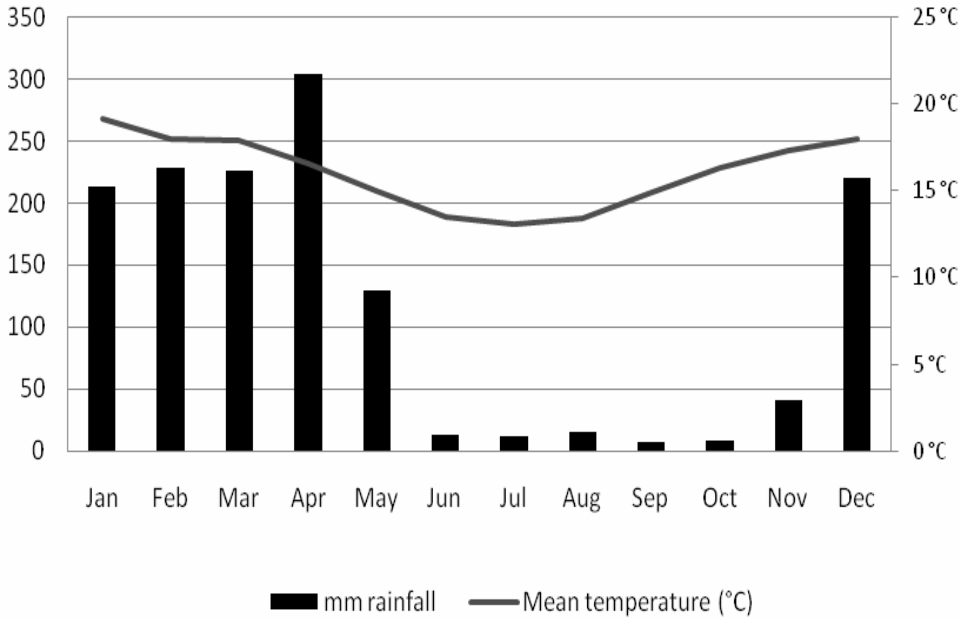


Figure 7: Annual mean rainfall and temperatures for 2002-2009 Iringa regions, Tanzania

Source: GRL (2010)

There are extensive areas of natural forests occurring in patches and fragmented landscapes, including part of Eastern Arc Mountains (Burgess *et al.*, 2007). Most of these natural forests are managed under PFM either under JFM or CBFM arrangements established from 1990s (HIMA, 1996).

3.3 Methods of Data Collection

3.3.1 The study design

Trochim (2006) defines research design as "the glue that holds the research project together. A design is used to structure the research, to show how samples or groups, measures, treatments or programs and methods work together to try to address the central research question." The use of with and without CBFM intervention was the method applied in this study as well as before and after through satellite image analysis for land use and cover change. The potential strength of optimization models is that they may simultaneously or recursively relate complex interactions in both the bio-physical and socio-economic systems (Hennigar *et al.*, 2008; Buongiorno*et al.*, 2012). By bringing in the rational behaviour of the key decision maker and strictly controlthe environment (*certulis peribus* assumptions), it is possible to do with and without experiments (Hennigar *et al.*, 2008).

3.3.2 Sample size determination

Nachimias and Nachimias (1996) *argue* that sample size is one of the most important determinants of survey estimates, and that depends on precision (amount of sampling error that can be tolerated by the researcher) and confidence level (level of certainty that the true value of the variable being studied is captured within starndard error or sampling error). The authors argue further that the greater the precision of estimate and confidence in the results, the larger the sample size needed. The authors furthermore posit that another factor, equally important, in determining the sample size is the amount of resources (time, money and personel) available for the study. According to Gay and Diehl (1992), generally the number of respondents for the study depends on the type of reseach involved: descriptive, correlational, or experimental. For descriptive reseach, sample should be 10% of the population. But if the population is small, then 20% of the population may be required. For correlational reseach at least 30 subjects are required to establish the relationdhip. For experimental reseach, 30 subjects per group are often cited as the minimum.

Thisstudy used two main types of data sets, ecological and socio-economic which were collected in three different phases. Phase one involved reconnaissance survey carried out prior to actual data collection. The second phase involved collection of ecological data through the use of forest inventory techniques, including satellite imagery for land use and cover change detection. The third phase was collection of socio-economic data which involved household's questionnaire survey. The sample size adopted for household questionnaire survey was at least 10% of the target population. In addition, Participatory Rural Apprasal (PRA), key informant interviews, focused group discussions and participant's observation was also used. The application of different techniques helped to compliment limitation that could be contributed by one technique. This allowed cross checking and verification, commonly known as triangulation (Nachimias and Nachimias, 1996). The sample size for ecological data relied on the reconnaissance survey results carried out in all selected miombo woodlands.

3.3.3 Reconnaissance survey

Reconnaissance survey familiarised the researcher with the study sites and units of analysis before actual data collection. At this stage the socio-economic data collection tools were also tested and modified accordingly. This also enlightened the researcher on other logistical issues that would contribute to the success of data collection exercise. Forest inventory reconnaissance survey involved tree species identification (Appendix 1), examination of forest boundaries and determination of basal area per ha (G).

The objective of doing this was to estimate the population variation and number of sample plots needed in carrying out actual inventory.

A total of 15 plots were used with precision of 10% to compute required number of plots as suggested by IPCC, Good Practice Guidance (2003). Plots sample size (n) was computed as;

$n=\frac{CV^2 * t^2}{E^2}=\frac{\left(\frac{SD}{X}\right)^2 * t^2}{E^2}$ Where: CV = Coefficient of variation; *t* = the value of *t* obtained from the students' distributionTable at n-1 degree of freedom, SD = Standard deviation and X = Mean of basal area.

According to IPCC (2003) recommendable forest inventory precision is 5% to 10% depending on the size of the forest. However, Zahabu (2008) argued that given the nature of Tanzanian natural forests with fragmented, degraded and intact patches, sampling error of up to 10% is recommendable. In this study, compromise was made between precision required and the cost and there by sampling error of 10% was used.

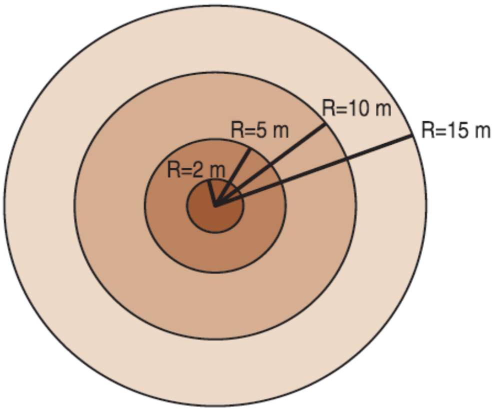
3.3.4 Sampling procedure

Purposive sampling procedure was employed in selecting region, districts and villages which suits the objective of this study. The selection criteria were availability of miombo woodlands under community based forest management and adjacent business as usual forest for comparisons. Villages for socio-economic data were selected based on the criterion of closeness to miombo forest reserve and practice CBFM intervention. The sampling frame was the village registers showing total number of households in the village. Households were then chosen by simple random sampling techniques using random number table. This increased the level of accuracy and precision of variety of the circumstances that could have profound effect on forests.

3.3.5 Collection of forest based information

Concentric circular plots of maximum radius of 15m (Figure 8) and prepared field formswere used in forest based data collection. The concentric plots aimed at increasing the accuracy of the measurement and sampling intensity of larger trees as well as saves time (URT, 2015). The plots were systematically laid out along transects at an interval of 200m and the 200m between plot intervals. Transect orientation was based on spatial distribution of road network passing through the forests (Plate 1). The first sample plot was randomly determined so as to minimize the edge effect. Plot centre for the first plot was laid half the prescribed plot interval from the road edge. With this sample plot of 15m radius, equivalent to 0.07 ha or (700m^2), plot number, slope, aspect, vegetation type and corresponding coordinates was recorded. The hand held GPS (Garmin GPS map etrex 60 CSx) receiver of a precision of ±3M was used. This plot size was also comparable with the spatial resolution of Landsat TM and ETM+ (FAO, 2007; Kashinde *et al.*, 2013). However, these satellite imageries were also used to detect vegetation cover change before and after community based intervention.

The following measurements and visual assessments were done for individual trees, stump and other disturbances in each plot: Radius 2m**:** Measure and record diameter of all trees with DBH $\geq$ 1 cm and identify the tree species, this helped to understand the regeneration potentials in the forest. Radius 5m: identify the tree species and measure the diameter of all trees with DBH $\geq$ 5 cm. Radius 10m: Measure and record diameter of all trees with DBH $\geq$ 10 cm and also identified the tree species. Radius 15m: Measure and record diameter of all trees with DBH $\geq$ 20 cm and identified the tree species as detailed in Figure 8. According to Aboal *et al.* (2005) the diameter at breast height gives an idea of tree volume and locally available allometric equations can be applied to forest inventory data to assess the biomass and carbon stocks of forests.



Radius:15m
Trees:DBH ≥ 20cm
Radius:10m
Trees:DBH ≥ 10cm
Radius:5m
Trees:DBH ≥ 5cm
Radius: 2m
Trees: DBH ≥ 1cm

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Plate 1: A scene during forest measurement of stocking parameters at one of CBFM forest while village elders doing species identification

(Photo by Research Team Member July, 2013)

Since there were no records of legally and illegally harvested trees, basal diameter of stumps at 30cm above the ground for harvested trees in both CBFM and BAU managed woodlands were measured to estimate volume removals from the forest. Stumps of harvested trees were described as ‘new’ if the stumps were fresh (harvested within one year) and ‘old’ if there is blackening on the stump harvested in the previous year or more (Plate 2). This approach was also used in previous disturbance studies in Tanzania (Mbwambo *et al.,* 2012; Sangeda, 2013). Three sample trees in each plot from DBH classes were randomly selected and measured for basal diameter (BD cm), DBH and height (H in metre). All measured tree species and stumps were identified with the help tree species checklist and local botanist. Other types of human disturbances such as mining, hunting, charcoal making, forest fires and grazing were recorded throughout the survey.

Plate 2: A scene during forest ecological data collection at a BAU forest while village elders doing species identification by vernacular names

(Photo by Research Team Member July, 2013)

In addition, Landsat images for 2000 before CBFM and 2013 after CBFM were used to analyze land use and miombo woodlands cover changes. All images were acquired during dry season between June, July, and September so as to minimize seasonality and cloud. The image Landsat ETM+ with Path/Row 168/66 and acquisition date 28th/09/2013 and 168/65 of 10/07/2013 was used to detect change after ten years of CBFM implementation, while the image Landsat TM with Path/Row 168/66 and acquisition date 18th/06/2000 and 168/65 of 24th/09/2000 was used to analyze before CBFM as a relative base case.

3.3.6 Collection of socio-economic data

3.3.6.1 Participatory rural appraisal

Participatory Rural Appraisal (PRA) methods are well suited for the REDD+ assessment because they are based on the premise that community voices are essential for policy development and implementation. Both qualitative and quantitative data were captured to address the socio-economic context of local community and forest dependence levels. PRA methods used included participatory resource mapping, group discussion, historical charts, field-based observation, scoring and ranking exercises. The mixing of these PRA methods offered a creative approach to enable information sharing and increased accuracy. In PRA, villagers with minimum level of formal education can comfortably participate in data collection and assurance of getting useful information is maximised. The PRA methods promoted interactive learning, sharing of knowledge and flexible structural and content analysis of the socio-economic data.

3.3.6.2 Focusgroup discussion

Focused group discussion aimed at gaining more information on issues pertaining to the community based forest management and utilization. Group members from village committees, such as village environmental committee (VECs), and village community bank (VICOBA), Social and welfare and planning committees were involved. To ensure that the objectives of the study are well captured in the discussion a written guideline of questions was used. In this focus group discussion, issues of forest management activities and whether the forest stock is enhanced due to community based forest management was discussed. Other questions addressed forest resource use as well as their opinions with regards to REDD+ initiatives. During the discussion, the follow-up questions were also asked immediately as an interesting point was mentioned. The discussion was very useful in gaining a deeper understanding, crosschecking and supplementing information for important socio-economic issues, including some variables to use in optimisation study.

3.3.6.3 Participatory resource mapping

Participatory resource mapping is a tool designed to gain information about communities and their resource use. This technique was used to obtain information about land use activities and forest resources base as perceived by villagers themselves. The mapping delineated village boarders, the forest resource, agricultural fields, rivers and all other designations. However, the resource use matrix was used to explore and quantify forest resource use more systematically. In this exercise, a set of items were used to indicate place of collection i.e. from community forest or general lands and or woodlots in their surroundings and ranked based on its relative importance in the village and estimated amount collected per year. The matrix also used to identify the principle users and associated price as well as collection costs of the various forest products.

3.3.6.4 Household questionnaire survey

Household questionnaire survey was used to collect socio-economic data from households through face-to face interview. The questionnaire comprised both closed and open-ended questions and was administered to the head of households. The questions examined the aspects of household forest resource use including wood products and NTFPs, livelihood activities, labour distribution by sex and age as well as participation in forest management activities. In the first part of the questionnaire respondents were asked about demographic and income sources. Information collected in the subsequent sections included forest dependence and management issues. The questionnaire also included quantification of forest products use, price and associated costs as well as contribution to household's livelihoods.

3.3.6.5 Key informant interview

Key informants interviewed include government officials i.e. forest officers and agriculture extension officers, local leaders and elders, NGO officials working in the villages and business persons who are influential in the village. Some of these key informants were pre-determined but some were just meet during PRA exercise or while walking in the village. The key features which were emphasized here include cumulative learning, a semi-structured and flexible data collection approach. A prepared checklist was used to guide the interview. The interview was kept flexible and was done with a single participant. This technique was also used to verify some of the optimisation study data obtained from literature search and or from other sources.

3.3.6.6 Direct observation

The researcher went into the field to validate and document some land use and forest management activities practiced. In this method, a researcher was able to take notes on the local community's day to day livelihood activities and record some of the socio-economic indicators. The information included forest product collection and utilization, price, sale of forest products and services. In addition, an appraisal in various urban and village markets including rural roadsides provided latest market prices of products i.e.

price of charcoal and firewood’s, poles, logs and honey. The methods helped the researcher to understand better the local community’s attitudes, perceptions, motives and constraints on issues related to miombo woodland management and utilization.

3.3.6.7 Secondary data

Collection of secondary data was a continuous process that carried out during the entire study period. Secondary information were collected from Sokoine National Agricultural Library (SNAL), University of Life Sciences in Norway, Tanzania Forest Research Institute (TAFORI), the library of University of Dodoma, Institute of Resource Assessment of University of Dar Es Salaam (IRA), Tanzania Forest Conservation Group (TFCG) and MEMA, project in Iringa region. Moreover, a comprehensive literature search had been performed using databases such as ISI web of knowledge, Science Direct, Wiley Inter science and CAB Abstracts. The search used the keyword terms: forest management and carbon accounting, carbon sequestration, carbon sinks, forestry and land use change, tropical forests and woodlands, miombo woodlands, Tanzania. The references obtained from interesting articles were used in additional search, however, the selection was somehow arbitrary, but covered the most important aspects of the present study. Some of the outcome of this literature search has been published as a review paper (Lupala *et al.*, 2014).

3.4 Data Analysis

3.4.1 Ecological data analysis

Tree species lists and codes were prepared and the diameter at breast height (dbh) entered in excel spreadsheet. Forest parameters (stem density, basal area, volume and biomass as well as carbon stock) were computed. This determined forest stocking, tree species composition, structures and regeneration patterns. The analysis helped to understand the productivity and sustainability of the forest. The biomass and then carbon stock potentials of all measured trees per hectare were derived from the number of individuals recorded in the sample plots from the CBFM and non-CBFM areas. A two-tailed test at 5% level of significance was used to draw statistical inference on the existing difference in management regimes and between study sites.

3.4.2 Forest biomass computation and carbon stock estimation

The selection of appropriate allometric equations for computation of both above ground biomass (AGB) and below ground biomass (BGB) was done through pre-tested locally available allometric equations. The general allometric equations for $AGB = 0.1027D^{2.4798}$ and $BGB = 0.2113D^{1.9838}$ computation by Mugasha *et al*. (2014) was used. Where biomass= total tree biomass (kg) and D = tree dbh (cm). This equation includes trees greater than 1 cm diameter at breast height (dbh) and it has the advantage of requiring only dbh as independent variable. Among others, the equation included miombo woodlands from Iringa region and also had R^2 of 95% making it most reliable. The use of local allometric equations for areas with similar geographical and vegetation type is recommended in the literature (Brown, 2003; IPCC, 2003; Mugasha *et al.*, 2014). Biomass was then converted to carbon using biomass carbon ratio of 0.48 and then multiplied by 3.67 to get equivalent tCO_2/ha (URT, 2015).

The tree volume used the allometric equation ($V = 0.00016D^{2.463}$) developed by Mauya *et al.* (2014) for miombo woodlands of Tanzania. In addition, the total tree volume was calculated from the allometric equation developed by Mauya *et al.* (2014). The equation was: $V = 0.00016D^{2.463.}$ Where V= tree volume (m^3) and D= tree dbh (cm) ($R^2 = 0.87$). Harvested tree volumes were estimated by developing DBH-BD regression equations from measured sample trees.

3.4.3 Forest growth model

The entire forest represented at time t (inventory time) was indicated by the column vector $Tt = [Y_t], i = 1 \ldots\ldots, n$ during a specific growth period θ the trees in a given diameter class ì may remain in the same class or advance to a larger size class. Trees may also die during the interval θ, or they may be harvested. This is denoted by $h_{it}$the number of trees harvested from diameter class ì during the intervalθ. Therefore the entire harvest is represented by the column vector $ht = [hit], i = 1 \ldots\ldots, n$.. Furthermore, let (ai) be the probability that a live tree in size class i at time t which is not harvested during the intervalθ ill still be alive and in the same size class at time t +θ. Also (bi) be the probability that a live tree in size class $i - I$ at time t which is not harvested during the interval θ will be alive and in size class $i - t$ at time $t + \theta$. Finally, it designates the expected ingrowth, i.e. the expected number of trees entering the smallest size class during the interval θ. The situation of the stand at time $t + \theta$ may then be entirely determined from the situation at time t, the harvest during θ, and the ingrwth during by the n equations:-

$Y_{1t+\theta} = I_t + a_1(Y_{1t} - h_{1t})$ ……………………………………………………………………..1

$Y_{2t+\theta} = b_2(y_{1t} - h_{1t)} + a_2(y_{2t} - h_{2t})$ …………………………………………………………….2

$Y_{nt+\theta} = b_n(Y_{n-1t} - h_{n-1t}) + a_n(Y_{nt} - h_{nt})$ ……………………………………………………..3

To have complete growth model, a specific form must be given to the ingrowths function I_t. The simplest alternative would be to set I_t to a constant (Buongiorno and Michie, 1980). However a more flexible form would recognize that ingrowth is affected by the condition of the forest. According to Ek’^{s} (1974) observations suggest that ingrowths is inversely related to the basal area of the forest stand and that, for a given basal area, ingrowths is directly related to the number of trees. That is to say, other things being equal, ingrowths appear to be favoured by forests of small trees (e.g. Buongiorno *et al.*, 2012). Adoption of this concept let to an expected ingrowths function of the form

$I_t = \beta_0 + \boldsymbol{\beta_1} \sum_{t=1}^{n} B_i\,(Y_{it} - h_{it}) + \beta_2 \sum_{i=1}^{n} (Y_{it} - h_{it})$ ………………………………………… 4

With $I_t \geq 0$where $B_i$is the basal area of the tree of average diameter in size class i, whileβ_0,β_1 andβ_2 are constants which one would expect to be, respectively, positive, negative and positive (Buongiorno and Michie, 1980). This leads to a new expression for the number of trees in the smallest size class as a function of the number of trees in all size classes and of the harvest.

$Y_{1t+\theta} = \beta_0 + d_1(Y_{1t} - h_{1t}) + \cdots + d_n(Y_{nt} - h_{nt})$ ………………………………………… 5

Where$d_1 = a_1 + \beta_1 B_1 + \beta_2$

$d_i = \beta_1 B_i + \beta_2$ for $i > 1$>.

The final forest growth model takes the form$y_t + \theta = G_t(y_t - h_t) + C_t$ and $h_t \leq y_t$which is density-dependent matrix model developed and evaluated for woodland trees (Mugasha *et al.*, 2014) and endogenously forecast forest growth and biomass consumption. The optimization deals with steady state regimes in which the growth over the product harvesting compensate exactly for the harvest, so that the harvest could be continued in perpetuity. The harvest, h_t and the growing stock, y_t, that maximized the net present value from product harvest only, instead state, is given by the following non-linear optimization problem:-

$MaxNPV = \sum_t [\,\delta_t . Chr_t . A . (Pchr - cstI_t - csto_t)]$ ……………….……………………….6

Subject to: $Y_{t+1} = G_t(Y_t - h_t) + R_t$ ………………………………………………………..7

$h_t \geq 0$ ………………………………………………………….………..………………… 8

$y_t - h_t \geq 0$ ……………………………………………………………………………………… 9

3.4.4 Structure of the optimization model used

The objective function is to maximize the NPV of selling wood fuel (accounted as Charcoal in the model), Non Timber Forest Products (NTFP) and Carbon credits.

$$NPV = \sum_t [\, \delta_t . Chr_t . A . (Pchr - cstl_t - csto_t)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

This is an objective function for maximizing charcoal production assuming forest under CBFM is a production Village land Forest Reserve (VLFR) focusing on sustainable forest extraction.

δ_t =Discount factor, in our case calculated as $\delta_t = e^{-rt}$

$$NPV = \delta_{t.} (\sum_n [Pntfp\,.Wntfp.ERntfp.SQntfp] + [PCO_2.QCO_2.A] - CoMcbfm_t - CoOcbfm_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.11$$

This is an objective function for maximizing carbon storage for carbon credit, with assumption that miombo woodlands under CBFM can be used for both carbon credit sales and forest extraction to support livelihoods. To determine supply of forest products due to CBFM management regime with respect to growing stock that maximizes total net present value, including income from CO_2 sequestration where stored CO_2 have a price. The optimum management was expressed by the following equation:

$$MaxNPV = \sum_t [\, \delta_t . Chr_t . A . (Pchr - cstl_t - csto_t] + \delta_{t.} (\sum_n [Pntfp\,.Wntfp\,.ERntfp.SQntfp] + [PCO_2.QCO_2.A] - CoOcbfm_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..12$$

Where:

δ_t = Discount factor, in our case calculated as $\delta_t = e^{-rt}$

where r is the interest which for this study NPVs were computed at 3%, 6% and 9% .

$\delta_t = e^{-rt} =$ (3% = 0.97; 6%= 0.942; and 9%= 0.970)

$Pchr$ =The price of 1 kg of charcoal= TZS 14,000/-≈ 9.4 US$

A = The forest area under the study (ha) =2,969.65 ha

chr_t =The amount of biomass for charcoal production (t ha^{-1})= 0.75; 1.5; 2; 3; and ≥3.5

$cstl_t$ =The cost of hired labor to produce 1 kg of charcoal=7.59US$

$csto_t$ =Other costs to produce 1 kg of charcoal (tools, transport, bags, etc.)=6.4US$

$Pntfp$ = Price of NTFP /kg (mushroom TZS 1, 000/-≈ 0.7 US$; fruits TZS 500- ≈ 0.3; medicinal TZS 850/-≈ 0.6 US$

$Wntfp$ = Weight (kg) of NTFP per units of collection; mushroom (5kg/bucket), fruits (1kg/tin), medicinal (1kg/bundle)

$ERntfp$ =Estimated ratio of collection quantity to production of the forest based on respondents explanation (about 75%)

$SQntfp$ =Seasonal amount of NTFP collected from forest 28.56; 468.72; 69.24

PCO_2 =Price of carbon (5US$)

QCO_2 =Amount of tCO_2 available for sale in carbon market annually from the forest (carbon from annual biomass increment minus allowable harvest)

$CoMcbfm_t =$ Costs /ha (labour) in CBFM management for REDD+ = US$1,580/ha (Zahabu, 2008)

$CoOcbfm_t =$ Other costs of REDD+ = UD$ 22961.48 (Opportunity & transaction)

Where NPV is the combined net present value from forest product harvest and CO_2stock over the planning horizon in this case 45 years was arbitrary chosen. Some analogies and differences with respect to the model of interrelated growth and harvests proposed by Buongiorno *et al.* (2012) have been observed. It should be noted that some of the assumptions adopted concerning the model structure (equilibrium conditions, applicability in mult-species forest and various use value of the forest products from miombo woodlands, constancy of the coefficients in the years and neglect of interactions among forest products use and other goods and services from different land uses can appear tenuous or oversimplification from a theoretical point of view. On the other hands, many of them are usually accepted in other models for optimal harvesting (Nammalwa *et* *al.*, 2007; Hennigar *et al.*, 2008). These assumptions provide a practical way to develop a useful tool for the optimization of community based forest management for carbon stock and local livelihoods within miombo woodlands of Tanzania.

3.4.5 Model scenarios

Six different model scenarios were analyzed (Table 5), each with a planning horizon of 45 years, that is 2000-2045. The first scenario is an attempt to generate a development that a forest is left under common access regime termed as business as usual (BAU). The access is free and unregulated, possibly because rights are only nominal and unforced (Adhikari, 2005). The second scenarios is under community based management regime (CBFM), where communities continue to manage forest with the objective of meeting their subsistence need from the forest and do sell carbon credits for any increase in carbon stock that occur. The off-take permitted is less than the mean annual increment of the miombo woodlands, meaning that the management is sustainable and forest stock tends to increase. The benefits derived from this management are fuel wood, non-timber forest products (NTFPs) and carbon credit sold in voluntary market. The carbon storage and sequestration is thus net, after fuel wood and other NTFP extraction to support local livelihoods as agreed in the management plan.

Table 5: Overview of model scenarios

No	**Scenario**	**Abbreviation**	**Constraints**
1	Business as usual	BAU	Unsustainable use >3.5 m^3 ha^{-1}
2	Community management	CBFM	Sustainable harvest is allowed = 3 m^3ha^{-1}
3	Carbon credit only	CCO	Total protection = no harvest
4	Strict quota on forest use	SQ	Harvesting ≤ 1.5m^3/ha^{-1}
5	Medium quota on forest use	QM	Harvesting ≤ 0.75m^2/ha^{-1}
6	Loose quota on forest use	QL	Harvesting ≤ 2.0m^3/ha^{-1}

The third scenario is reflecting forest management for carbon credit only policy. The purpose of this scenario was to see how a strict implementation of the ban on harvesting would affect forest biomass development and local community livelihoods. The fourth, fifth and six scenarios allow the local communities to extract forest produce, but the number of produce must not exceed a certain quota. The policy of using quotas to limit level of forest extraction was motivated by the aim of good compromise between local livelihoods dependence in forest resource and biomass for carbon storage. It seemed unrealistic to expect local community to stop forest extraction completely for the sake of carbon credit income. Therefore it was assumed that it would be possible to find a better solution through establishing quotas.

In order to determine optimal harvest rate, one cubic meter of wood yields 4.3 bags of charcoal (56 kg/bag), and the labor required to produce one bag of charcoal is 2.3 person-days (Hofstad 1997; Luoga *et al*. 2002). Charcoal producers earn a little more than the worth of their labour and cost of other inputs in the production is minimal (Hofstad and Merely, 2014). The cost of physical inputs, such as axes, machetes, and rope, is approximately USD 6.4. Some of the wood from adjacent open access forest is normally free of charge since the licensing system is far from effective (Lund, 2008). Agricultural rent was made for estimating cost of labor required for different activities such as felling and cross-cutting of trees, log piling, stacking, and loading and unloading charcoal kilns.

Based on intensive literature review the following mean annual increments (MAI) were observed from several miombo woodlands sites of Tanzania. In Morogoro MAI of 0.57-2.97t/ha/year for mature trees, while for young or exploited miombo woodlands MAI range from 0.7 - 4.2t/ha/year (Ek, 1994). The increment is vigorous for the young miombo woodlands which may range from 1.2 to 3.4 tons per ha, equivalent to 4–7% of above-ground biomass (CHAPOSA, 2002). The MAI in miombo woodland biomass depends on species composition, amount of rainfall, and soil factors (Frost, 1996; Chidumayo, 2013).

Since the optimization is made from the local community point of view and due to the rather low level of income and wealth in miombo woodlands of Tanzania (Abdallah and Monela, 2007), it was assumed that a discount rate above the average growth rate is a reasonable approximation to villagers behaviour. In this type of analysis the interest rate has great impact on the results. The model was therefore run with 3%, 6% and 10% interest rate for sensitivity detection.

3.4.6 Ethical consideration in the present study

The study adhered to ethical principles including informed consent and confidentiality to the extent that will not compromise objectives of the study. Prior to field visits for implementation the introduction letter from Sokoine University of Agriculture (SUA) that introduced me to the district administration including descriptionof the objectives of my research was done. During the household survey it was unethical for the author who is a young man to ask an elder household head about his/her marital status and a number of children he/she has. So the researcher had to find a soft language that indirectly gave information required without embarrassing the respondent. Another important issue within social research ethics is the principle of informed consent. This means that the study communities are given enough information to be able to make an informed decision about whether they wish to allow and participate in the study or not. According to Scheyvens *et al.* (2009), it is assumed thata person has a complete and thorough understanding of the aims and processes of the research project prior to implementation. Therefore before the interview started, I always gave a thorough clarification about my study in general and the interview in particular to the respondents. Anonymityand confidentiality is another ethical aspect in social research whereby the researcher makes sure that the respondents/informants' identities remain hidden. I have also striven to ensure confidentiality of all sensitive personal information of respondents and their household members throughout the study.

CHAPTER FOUR

4.0 CHARACTERISTICS OF RESPONDENTS

4.1 Introduction

This chapter highlights characteristics of respondents focusing on socio-economic characteristics, demographic characteristic of respondents, wealth status and perception of importance of community based forest management. There after the preceding chapters using published papers and manuscript as an outcome of this study are attached as separate chapter. Chapter five provide review paper on management and carbon stock in miombo woodlands, chapter six land uses and cover change as influenced by community based management, chapter seven potential of voluntary carbon market and chapter eight is the manuscript submitted for publication on the optimising community based forest management.

4.2 Socio-economic characteristics of respondents

The socio-economic characteristics for 218 respondents who took part in this study are presented in Table 6. More males headed households (78%) participated as compared to female headed households (22%). Education is an important issue in the development of livelihood strategies and understanding of the issues patterning to climate change mitigation and carbon trade. In the study area respondents with primary education dominated (67%) as compared to other respondents. Education is normally considered as key to improved opportunities for development and access to information. This is therefore important in developing sustainable forest management and climate change mitigation strategies.

Table 6: Socio-economic characteristic of respondents

S/N	Characteristics	N (218)	Percent
1	Respondents		
	Household head	126	58
	No household head	92	42
2	Gender of household head		
	Male-headed house holds	170	78
	Female –headed households	48	22
3	Marital status of respondents		
	Married	157	72
	Not married	20	9.2
	Widowed	16	7.4
	Divorced	11	5.0
	Separated	14	6.4
4	Educational level of households head		
	No formal education	10	4.6
	Primary education	146	67
	Secondary education	39	17.8
	Adult education	8	3.7
	Tertiary education	12	5.5
	University education	3	1.4
5	Main occupation of household head		
	Employee	32	14.7
	Retired	8	3.7
	Causal labor	16	7.3
	Farmer	133	61
	Trader/shopkeeper	6	2.8
	Petty business	18	8.3
	Others	5	2.3

The occupation of households head were mainly farming (61%), implying that agriculture is main economic activities in the study area. Furthermore, it was revealed that 39.9% of respondents have income ranging between USD 300-500 per year and few respondents have more than USD 1000 per year (Table 7). Based on this income category, the participatory rural appraisal ranked respondents into three wealth classes. More respondents were ranked in medium wealth category and very few were ranked in the category of better off.

Table 7: Distribution of household's monthly income from various socio-economic activities

S/N	Descriptor	N =218)	Percent
1	Income category (USD)/year		
	< 300	37	17
	300-500	87	39.9
	>500-1000	58	26.6
	>1000	36	16.5
2	Wealth category		
	Poor	52	23.9
	Medium	112	51.4
	Better off	54	24.7

Estimated household income per month was tested statistically between the two districts. T-statistics test was done to compare annual income earning between the study communities from two districts and revealed that there was no difference in household annual income between the districts at P > 0.05 (Table 8).

Table 8: Result from t-statistical test comparing annual income of the study communities of Mufindi and Iringa rural districts

t-Test: Two-Sample Assuming Equal Variances	Mufindi	Iringa rural
Mean	451 320.75	446 428.57
Variance	234.36	372.03
Observations	106	112
Pooled Variance	305.1111485	
Hypothesized Mean Difference	0	
df	216	
t Stat	0.282126845	
P(T<=t) one-tail	0.389058192	
t Critical one-tail	1.651938652	
P(T<=t) two-tail	0.778116384	
t Critical two-tail	1.971007422	

The wealth category classification among the households based several criteria including quality of housing, valuable goods owned, cash income and quantity of agriculture production including from livestock and crop farming (Table 9). About 70% of respondents owned bicycles; about 10% of respondents had petty businesses, apart from farming. About 26% of respondents owned plough, 5% owned cars or trucks, and 26% owned motorbikes 5% owned draught animals (oxen or donkey).

Table 9: Wealth categories and the criteria established by respondents

Rich: at least a household has	• A private car, modern house with bricks roofed with iron or tiles; **OR** • Practicing mechanized agriculture, having large number of cattle and oxen. Also harvest much thus use vehicle for crops transportation from farm to homestead; **OR** • Has employment with good salary, or other commercial business with good housing and a private car,
Middle class: at least a household has	• Quality house with brick walls and roofing of iron materials. Also milling machine, hand set ,radio, bicycle, ox-cart, bicycled, • Also harvest much thus use vehicle for crops transportation from farm to homesteads. • Have petty business (kiosk, brewing and crops dealers as middle men from farm to local markets)
Poor at most household common asset:	• Housing with walls made of mud and/or poles and roofed by grass thatches • Shortage of quantity and quality health meals of a day • Own none of the wealth assets and earn less cash that cannot afford school wear for children and schooling facilities for normal government primary school.

The major economic activities in the study districts is agriculture through subsistence farming and farmers often own scattered pieces of lands usually less than 5 acres. Both Iringa rural and Mufindi districts, between 70 to 80 percent of the original forest cover were removed to make way for agricultural land uses (URT, 2007). Livestock keeping is practiced in small scale and generally local communities depend on agricultural and forest products and services to a large extent for livelihoods. Apart from forests providing favourable climate for communities and supportive to the subsistence farming, forest products especially firewood and charcoal is the major source of energy (Figure 9).

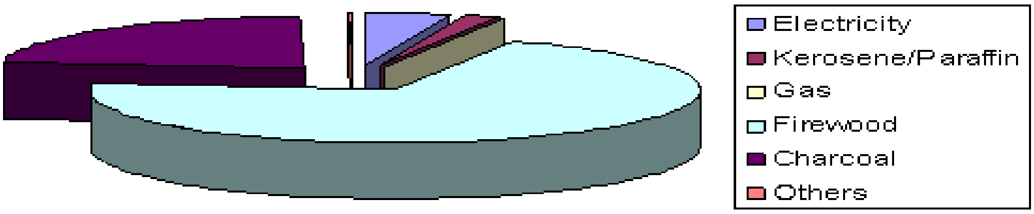

Figure 9: Main sources of energy for cooking in Iringa region.

Source: URT (2007)

Nonetheless, the study districts continue to host tropical closed forests and large area of dry miombo woodlands that remain important habitats for biodiversity. Apart from the large commercial farms in the study area, the dominating household average farm size is about one hectare or less and with six persons per household (URT, 2007). Markets for agricultural outputs are heavily influenced by distance to town centres, road densities, processing industries and of course general prosperity levels of the community. The households are mainly producers and consumers of major forest and agricultural goods. Labor is mainly provided by the household members and farm labor peaks occur during planting and harvesting seasons.

4.3 Demographic characteristics of respondents

Tanzania is sparsely populated with population density of 51 which is much higher compared to Iringa region which has 27 persons per square kilometre with variation across the landscape (URT, 2012). The overall country population has more than tripled from 12.3 million in 1967 to 44.9 million in 2012 (Figure 10).

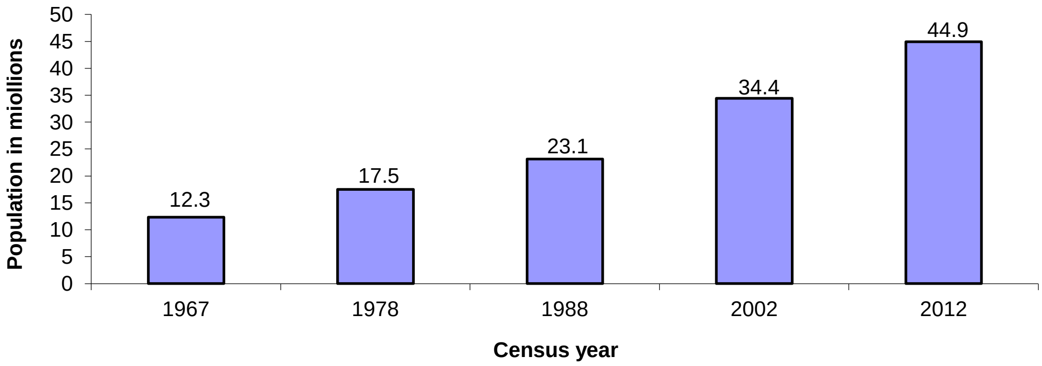

Figure 10: Overall population trend in Tanzania as from 1967 to 2012

Source: URT (2012)

The general growth is declining from 3.3% in 1967 to 2.7% in 2012 with the average household size remained constant 4.9 in year 2002 and 4.8 in 2012 census (URT, 2012). According to URT (2002) population density within Iringa region per districts remained low compared to the national average, but Iringa rural district have low population density compared to the Mufindi district (Table 10).The general population growth rates have slowed recently as a result of urban migration and higher death rates from AIDS and malaria (URT, 2012).

Table 10: Population density by district, Iringa Region, 2012

District	Land Area	Percentage cover	2012 Population	Population Density 2012
Iringa Urban	160.3	0.295	106 371	664
Iringa Rural *	19 897.5	36.64	254 032	12
Kilolo	6804.0	12.53	204 372	30
Njombe	9 868.0	18.17	419 115	42
Makete	5 800.0	10.68	105 775	33
Mufindi*	6 177.0	11.38	265 071	46
Ludewa	5 597.0	10.31	128 155	23
Total Region	**51 681.8**	**100**	**1 490 892**	**29**

Source: URT(2012) *Study districts

Major ethnic groups in Iringa region and particularly Iringa rural and Mufindi districts are Hehe who constitute about (43%), Bena (37%) and Kinga and Pangwa make up (11%) of the entire population, there are about 3 percent of other indigenous people in the regions (URT, 2007). The average household size were found to be 5 ±2 persons in the 218 number of households participated in this study (Figure 11), while the average age was 45±17 years. This implies that the respondents who participated in this study were of adult age group.

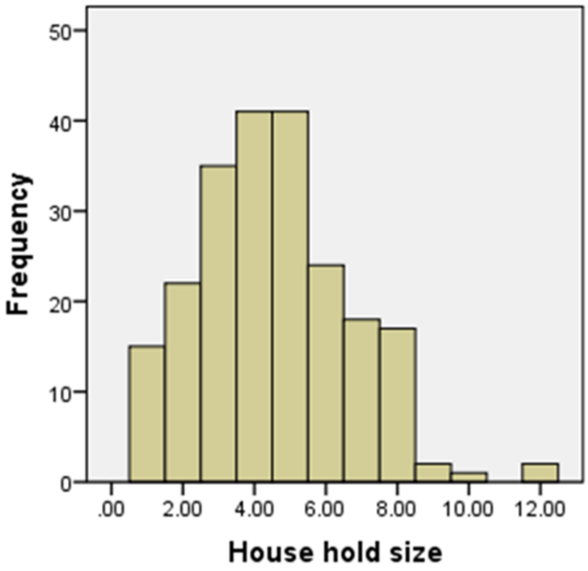

Figure 11: Household size of the study area (n=218)

4.4 Perception on the Importance of Community Based Forest Management

The respondents' opinion was sought over the popular notion that forests under CBFM are more important than their counterpart BAU forests. As expected, there were mixed responses (Figure 12). More than 60% of respondents revealed the CBFM managed forest is more important and that was the reason for them to manage it more sustainable.

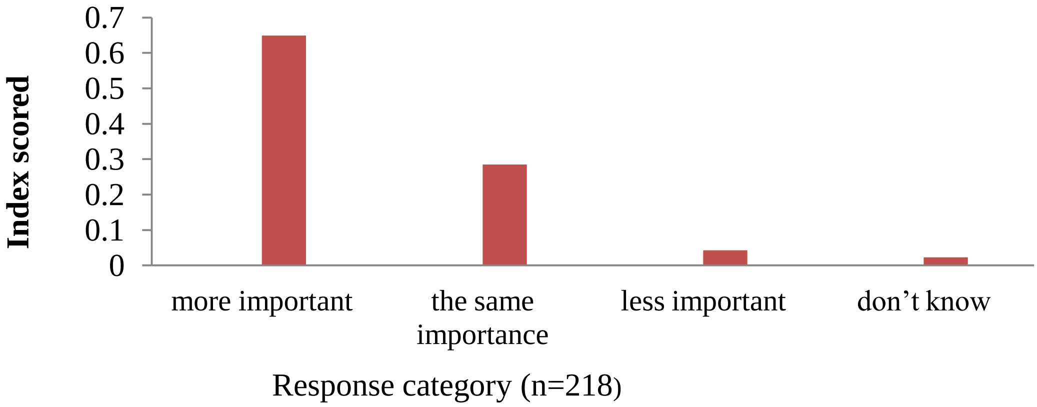

Figure 12: Local communities' perception on the importance of CBFM

Local communities found to extract variety of forest products throughout the year for their daily subsistence and income generation. However these products are collected from both CBFM and non-CBFM miombo woodlands (Table 11). Local communities found to extract variety of forest products throughout the year for their daily subsistence and income generation. These products are collected from both CBFM and non-CBFM miombo woodlands. The sustainability of forest extraction is controlled particularly in CBFM managed miombo woodlands.

Table 11: Forest products extracted from CBFM and non-CBFM in the study sites

Forest product	Response that the product is from CBFM only (%)	Response that the product is from non-CBFM only (%)	Response that the product is from both CBFM and non=CBFM (%)
Firewood	4.4	74.9	20.7
Fruits	5.1	64.6	30.4
Charcoal	16.7	66.6	16.7
Honey	2.3	56	21
Mushroom	18.7	43.9	37.4
Local medicine	11.4	49.4	39.3
Poles	62	59.4	34.4
Thatch grass	0	63.6	36.4
Timber	0	21.6	78.4

CHAPTER FIVE

5.0 PAPERS AND MANUSCRIPT BASED ON THE STUDY

5.1 Introduction

This chapter presents list of published papers and manuscript as an effort to address research objectives. Paper I explored the state of art management; growth and carbon storage in miombo woodlands based on literature review. The investigation of land use and cover change in miombo woodlands as influenced by community based forest management and its implication to climate change mitigation (Paper II). This provided necessary insight on forest management performance and land use change. The extent of carbon stock in community based forest management was explored in comparison to business as usual scenario selected in proximity. The emerging carbon markets for community based forest management were examined in order to have full knowledge of the carbon market and its opportunities available for CBFM (Paper III). Moreover, a feasibility analysis was performed to check the likelihoods of carbon project development in the study area (Paper IV). All these preliminary information and published papers enabled the development of an optimisation model for biomass management of Tanzanian miombo woodlands which was presented (Paper V). The optimal biomass management by means of mathematical programming techniques has been useful to simultaneously trade-off many competing objectives. In most cases, the variable optimised is resource harvesting efforts and biomass increments distributed over different time horizons, objective function and constraints. The objectives and constraints take into account economic aspect, biological growth patterns of miombo woodlands and management intervention.

5.2 List of Papers and Manuscript Presented

Paper I: Lupala, Z. J., Lusambo, L.P., Ngaga, Y.M., 2014. Management, growth and carbon storage in miombo woodlands of Tanzania.*A review paper. International Journal of Forestry Research*.DOI: 10.1155/2014/629317. (The paper is in pdf. file attached)

Paper II: Lupala, Z. J., Lusambo, L.P., Ngaga, Y.M and Angelingis A. Makatta., 2015. The Land Use and Cover Change in Miombo woodlands under Community Based Forestry Management and its implication to climate change Mitigation. A case of Southern Highlands of Tanzania. *International Journal of Forestry Research*.DOI: 10.1155/2015/459102. (The paper is in pdf. file attached

Paper III: Lupala, Z. J., Lusambo, L.P., Ngaga, Y.M., 2015. Potential of Voluntary Carbon Markets for Improved Carbon stock in Community Based Forest Management of Miombo woodlands, Tanzania.*Journal of Global Ecology and Environment, ISSN No. 2454-2644.Vol. 3 Issue 4.* (The paper is in pdf. file attached)

Paper IV: Lupala, Z.J., Lusambo, L.P. and Ngaga, Y.M. (2017) Feasibility of Community Management of Miombo Woodlands for Carbon Project in Southern Highlands of Tanzania *International Journal of Ecology*. ID 8965983, https://doi.org/10.1155/2017/8965983

Paper V: Lupala, Z.J., Lusambo, L.P., Ngaga, Y.M. and Makatta, A. A. (2017). Optimizing biomass in Community Based Forest Management for climate change mitigation and local Livelihoods in miombo woodlands of Tanzania. (Manuscript).

Paper I

Paper II:

Paper III:

Paper IV:

Paper V

CHAPTER SIX

6.0 SYNTHESIS OF THE STUDY

6.1 Overall discussion

The overall results from this study have shown that CBFM in miombo woodlands of Tanzania have significantly improved biomass. The improved biomass provides economic potential through carbon sequestration and storage under REDD+ initiatives and its emerging global carbon markets. Miombo woodlands managed under CBFM provide diverse livelihoods portfolios for a large number of Tanzanians. Optimised biomass can significantly contribute to economic development and ecological services for both local and global environmental benefits. As noted in this study (Paper II and some correction made Appendix 2), CBFM has influenced land use and miombo woodlands cover change with positive implication to climate change mitigation strategy. Mainstreaming CBFM in climate change mitigation with optimised biomass is important to unlock the full potential of miombo woodlands ecosystem. Despite fuel wood extraction being major threat to miombo woodlands management as noted in paper (I), optimised biomass use can also enhance synergies between carbon stock for climate change mitigation and energy demand that otherwise might be overlooked. Similarly, the optimised biomass assists in internalizing positive externalities and minimizes negative externalities from REDD+ initiatives and land use change.

The economical optimum biomass use under CBFM depends critically on the relative value of improved biomass availablefor livelihood support and carbon stock. Factors influencing optimum resource use by local communities adjacent to miombo woodlands should be a subject for further research. One promising approach is to use Markov

Decision Process Models to integrate the data used in this study and add the uncertainty stemming from economic, biological and catastrophic events (Zhou *et al*., 2008).

The world is advocating payment for avoiding deforestation and forest degradation in developing countries including Tanzania under REDD+ initiative. This is timely considering that tropical deforestation and forest degradation accounts for more than 20% of all green house gases emission (Angelsen, 2008; UNFCCC, 2009). The Copenhagen Accord recognizes this and seems to favour a REDD+ option (UNFCCC, 2009). However the design and implementation of REDD+ policies under optimized biomass use is important given the complexity of the social, economic, environmental and political dimensions of deforestation. Many of the underlying causes of deforestation and forest degradation are generated outside the forest sector and alternative land uses tend to be more profitable than conserving forests (Paavola, 2008). This study developed under this motive and papers compiled in this thesis are the effort towards optimizing biomass in miombo woodlands under CBFM as climate change mitigation.

The study reviewed the existing scattered literature in this field of miombo woodland management, growth and carbon storage potentials (paper 1). This enabled the understanding of the state of art and utilization of miombo woodlands in Tanzania. The finding of paper 1 emphasize that despite the local livelihoods support provided by miombo woodlands, the growth has potential for carbon storage and sequestration and therefore attractive for REDD+ initiative. It recommended that climate change mitigation strategies should be made more innovative to optimize biomass for carbon storage and local livelihoods. This will help to secure availability of the goods and services upon which billions of local people alsodepend.

Determination of the effectiveness of community based forest management in influencing land use and cover change and its improvement in biomass for carbon stock in miombo woodlands of Tanzania published as paper II. The results provided the extent of forest cover and land use change in miombo woodlands as influenced by community based forest management. Furthermore, the improved biomass analyzed based on matching comparison of biomass from CBFM against without (business as usual) scenarios as baseline data. The ways in which these improvements have been observed in this study are additionally support tovarious empirical studies and multi-site analyses in Tanzania (Zahabu, 2008; Vyamana, 2009, Ngaga *et al.*, 2009). It adds tothe comprehensive publications that draw on more than multiple decades of CBFM experiences (e.g. Iddi and Bromley 2009, Lupala *et al.*, 2014). However, it was difficult to disentangle causality from CBFM using observational studies. The results of this study enabled the descriptionof the improvement in biomass, but not attribution to the causality. There remains a need to explain the cause –effect relations of the improved biomass for carbon stock due to CBFM. A quasi-experimental (e.g. matching-based) research design or longitudinal analysis using repeat-visit data would help to control for potential biases and facilitate more accurate analysis.

This study employed four CBFM managed miombo woodlands from Southern Highlands, Tanzania for triangulation purposes which provided insight on improved biomass for carbon stock and subsequent optimization for carbon credit. The improved biomass resulted from increased solidarity, cohesion, and social control of miombo woodlands illegal extractionunder CBFM. This further enhances permanence, reduces leakage, and increases accountability requirement for carbon credits. These are promising results can be enhanced through land use plan at village level and introduction of alternative income generating activities. It is among the best options to further reduce land use change and biomass loss in miombo woodlands.

Paper III gives analysis of the potential of voluntary carbon markets to community based forest management of Tanzania. Community based forest management is the principal strategy in managing miombo woodlands of Tanzania. Reducing emissions from deforestation and forest degradation and the role of sustainable forest management (REDD+) is considered as possible means for mitigating climate change (UNFCC, 2007). Voluntary carbon market which is emerging very rapidly is considered as important mechanism for community based forest management. However, the question remained on the potential of community based forest management from emerging voluntary global carbon markets. Do miombo woodlands under community based forest management of Tanzania contain significant carbon stock to be harnessed for voluntary carbon markets? What could be the implication of carbon trading to local livelihoods, this study has provided insight to this key questions.The finding from this paper provides important information and discussions for climate change mitigation policy development.

The study revealed that CBFM reduce deforestation and forest degradation in miombo woodlands of Southern highlands of Tanzania. There is significant improvement in biomass for carbon stock and sequestration need to be sold in the emerging markets. Based on economic analysis of this study it is concluded that voluntary carbon market is likely to deliver greater benefits at a lower cost than if the carbon market is ignored in community based management of miombo woodlands. Factors such as accountability, permanence, leakage and safe guard is important to be observed.

Although a deeper understanding of the causality of CBFM to the improved carbon stock is necessary to enable policy action, the study revealed significant potential NPV from improved carbon stock if sold in emerging market. The accounting of carbon verification costs under CBFM established by (Zahabu 2008) was used, but ideally these costs need to be customized and updated for the site and time specific data. Climate change mitigation policy should take advantage of already established CBFM institutions. CBFM needs to be strengthened to align better with these carbon markets. In addition, the market should focus on removing barriers such as rules and factors surrounding carbon trading to attract CBFM carbon projects.

Nevertheless, there is possibility for leakage of deforestation and forest degradation activities moving from one village to another. This can be reduced for example by enforcing existing community based forest management by laws across all villages and promotion of agro forest and tree planting activities. Also removing perverse incentives for deforestation and forest degradation and mainstreaming community based management to all miombo woodlands in Tanzania. A thorough understanding of the proximate and ultimate drivers of deforestation and forest degradation in miombo woodlands is still important. This will help estimation of the risk of leakage associated with developed mitigation strategies. An alternative approach is full participation by all villages would completely eliminate leakage in miombo woodlands.

Based on the findings in Paper I, II, III and IV an optimization biomass model for the community based forest management of miombo woodlands of Tanzania was developed in Paper V. The model development and application gave several interesting results. The results include the setting of appropriate targets for forest management change due to REDD+ initiatives that would increase community welfare. The study demonstrated that

CBFM has potential for climate change mitigation in miombo woodlands of Tanzania. Uncertainty remains, due to incomplete biophysical and socio-economic information. In this study many open areas that could be further developed for more reliable optimized biomass is provided. Despite of the limited information used in optimization, findings presented provide insight in describing community based forest management for both carbon storage and local livelihoods in miombo woodlands of Tanzania. These results have implication that appropriate policy should target in optimizing both carbon stock and local livelihoods needs, than just a single optimal value.

The emerging voluntary carbon market should be taped to capture carbon benefits for local livelihoods residing in miombo woodlands of Tanzania. Local community in community based forest management is the de facto managers of miombo woodlands. This management should be further explored and carbon mitigation projects implemented to motivate local communities. There still substantial gap concerning miombo woodland growth rate and household extraction rate estimation. This gap makes determination of appropriate optimal level of carbon storage capacity and local livelihoods support function to be yet challenging. Despite of this, the findings provide insights to guide REDD+ policy intervention to allow utilization of some miombo woodland products while enhancing carbon storage and sequestration to be credited. Further studies have to be performed in order to enhance model capabilities by including information from longitudinal data on miombo woodlands growth pattern, carrying capacity and trends of forest products utilization for better control of statistical reliability of the results.

CHAPTER SEVEN

7.0 KEY CONTRIBUTIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter highlights key contributions the present study has made to the body of knowledge. It also outlines areas that need further studies. The chapter further presents conclusions drawn from this study and highlights number of policy recommendations. The strategies that can be used to widely disseminate the findings of the present study have also been outlined in this chapter.

7.2 Key contributions of the study

One of the main problems with CBFM in miombo woodlands in Tanzania has limited tangible incentives for local communities to participate. CBFM experiences from various countries have shown that weak incentives to communities are the primary cause of the failure of sustainable forest management (Ostrom, 2009; Perman *et al.*, 2011). The government of Tanzania has been setting up CBFM as climate change mitigation strategy for both sustainable forest management and local livelihoods improvement. However, strength of this strategy is subject to the level of benefits derived from resource use and its contribution to local livelihoods. This in turn determines the level of motivation to fulfil obligations as laid out in UNFCCC and REDD+ strategy. This study provided substantial knowledge on how to optimize biomass under community based forest management for both local livelihoods and climate change mitigation. It has shown the potential of community based forest management in mitigation of climate change and local livelihood support through optimized biomass analysis. The study noted the significant biomass improvementfor carbon storage and sequestion.Despite of the observed improvement of biomass from CBFM and its potential for carbon stock and sequestration, the study demonstrated the importance of voluntary carbon market and possible economic gain to be taped. In addition, the economic feasibility of CBFM in miombo woodlands as carbon project has also been established.

Again it was found that it is almost imposable to adopt REDD+ implementation framework that will mean total protection in exchange of money gained because apart from income, the community needs forest products for consumption at households than might not be substituted with money from carbon credit and therefore optimization of forest resources utilization is pivotal to effective REDD+. Therefore the optimization of biomass and carbon storage for climate change through the developed model in this study is a crucial for this challenge. Total protections that will maximize carbon stock and ignore small scale extractions for community need seem to be a trap to REDD+ project managers as it will open a loophole for leakage.

The study has gone further to provide valuable information for academic and research community. Among the information provided include identified research gaps to be taken care in the future as further studies. For example the need for economic analysis of community based management of miombo woodlands and development of the optimization model using longitudinal data for more accuracy prediction. Four important scientific papers have been published in the present study. This is very important contribution to the literature and world of knowledge, particularly in sustainable forest management and climate change mitigation.

7.3 Conclusion

Optimization models are able to assist in setting appropriate targets for forest management change due to REDD+ initiatives that would increase community welfare.

The findings presented in this study and associated scientific papers provide insight in describing community based forest management for both carbon storage and local livelihoods improvement within miombo woodlands of Tanzania. The results of the biomass optimization analysis have implication that appropriate policy should target in optimizing biomass for both carbon sequestration and local livelihoods needs, than just a single optimal value. If REDD+ become an option in miombo woodlands under community based forest management regime, it is likely that will be opted by local communities if biomass use will be utilized to the optimal level as presented in this study.

Community based forest management improve biomass for carbon storage and sequestration and therefore have potential for both climate change mitigation and livelihood support. This study has revealed the average growth to be significant, despite the miombo woodlands serving as local community livelihoods support function. However, climate change mitigation strategy needs to be more innovative to optimize biomass for carbon storage and local livelihoods. This is important in forest-dependent communities like miombo woodlands. Carbon credits resulting from the increased carbon stock and sequestration should contribute to sustainable development. This should also help promote community based forest management and secure miombo woodland products and services upon which billions of people depend.This study revealedthat net present value from improved carbon stock if sold in emerging voluntary carbon market are likely to delivergreater benefits at a lower cost than if the carbon market is ignored.

7.4 Recommendations

Although a deeper understanding of the causality of CBFM to the improved carbon stock is still necessary to enable policy action, the study revealed significant potential Net Present Value (NPV) from improved carbon stock if sold in emerging Voluntary Carbon

Market.The accounting of carbon verification cost under CBFM established by Zahabu (2008) was used, but ideally these costs need to be customized and updated for the site and time specific data.Climate change mitigation policy should take advantage of already established CBFM institutions. However CBFM needs to be strengthened to align better with these carbon markets.In addition, the markets should focus on removing barriers such as rules and factors surrounding carbon trading to attract CBFM carbon projects.

7.5 Future Improvement Based on this Study

There still substantial gap concerning miombo woodland growth rate and per household extraction rate estimation. This gap make determination of appropriate optimal level of carbon storage capacity and local livelihoods support function challenging. However, this study finding provides best insights to guide REDD+ policy intervention in Tanzania. In order to allow utilization of some products while enhancing carbon storage and sequestration a prediction using time series data is necessary. This should be taken into account in further studies in order to enhance model capability. It should include information from longitudinal data about miombo woodlands growth pattern, carrying capacity and trends of forest products utilization for better control of statistical reliability of the results.

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APPENDICES

Appendix 1: Miombo woodlands tree species local, scientific, family name and its uses as observed in the study area

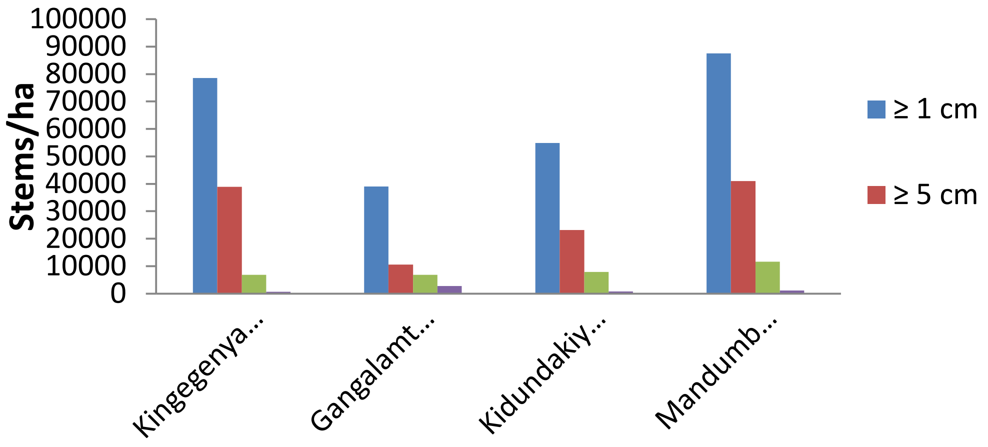
Code	Local (Hehe)	Scientific	Family	Uses
1	Mpembesa	*Brachystegia microphylla*	Fabaceae	Fuelwood, timber
2	Mpinati/mkwee	*Brachystegia spiciformis*	Fabaceae	Fuelwood, rope, timber
3	Mganga	*Berchemia discolor*	Rhamnaceae	Fuelwood
4	Mpombogati	*Vitex doniana*	Verbenaceae	Fruits, Timber
5	Mpalama (mlama)	*Combretum molle G.*	Combretaceae	Fuelwood, medicinal
6	Lihenyi	*Erythrina abyssinica*	Fabaceae	Medicinal
7	Mpingipingi	*Vangueria madagascariensis*	Rubiaceae	Medicinal
8	Mfagosi	*Erythrophloeum suaveolens*	Fabaceae	Firewood
9	Lihumbwe	*Mellera lobulata s.moore*	Acanthaceae	Medicinal
10	Mkusu	*Uapaca kirkiana*	Euphorbiaceae	Fruits, firewood
11	Mfwalugoti	*Uvariodendron oligocarpum*	Annonaceae	Fruits, firewood
12	Msaula	*Parinari curatellifolia*	Chrsobalanaceae	Fruits and firewood
13	Mvanga	*Zanha africana (Radlk.) Exell.*	Sapindaceae	Firewood
14	Lihuisa	*Bridelia micrantha*	Euphorbiaceae	Medicine, firewood
15	Mlelulelu	*Casearia battiscombei*	Flacourtiaceae	Timber, fire wood
16	Mgulumu	*Lannea schweinfurthii*	Anacardiaceae	Firewood
17	Libeketi	*Vangueria infausta Burch.*	Rubiaceae	Fuelwood
18	Mtungito	*Dombeya rotundifolia*	Sterculiaceae	Fuewl wood
19	Msilahange	*Pavetta schumanniana*	Rubiaceae	Medicinal, fuelwood
20	Mhenyi	*Faurea rochetiana*	Rubiaceae	Poles and firewood
21	myombo	*Brachystegia bohmii*	Fabaceae	Timber, fuelwood
23	Mpombokati	*Croton macrostachyus Del.*	Euphorbiaceae	Fuelwood
24	Mkwee	*Brachystegia spiciformis*	Fabaceae	Timber
25	Mtevele	*Coffea eugenioides*	Fabaceae	Food and fruits
26	Mtendeleti	*Brachystegia bussei*	Fabaceae	Timber, firewood
27	Mtono	*Commiphora africana*	Burseraceae	Medicinal
28	Mlungulungu	*Croton macrostachyus*	Euphorbiaceae	Medicinal, firewood
29	Mhanza	*Senna singueana*	Fabaceae	Medicine, firewood
30	Mdaha	*Euclea usambarensis*	Ebenaceae	Medicinal
31	Mtowo	*Azanza garckeana*	Bignoniaceae	Fruits, firewood
32	Mkongonza	*Opilia amentaceae*	Opiliaceae	Medicinal
33	Mdongadoga	*Vitex payos*	Lamiaceae	Fruits and timber
34	Msasati	*Psychotria schummaniana*	Rubiaceae	Fruit, medicinal

Code	Local (Hehe)	Scientific	Family	Uses
35	Mtundwa	*Ximenia cafra Sond.*	Olacaceae	Food, medicine and timber
36	Mgurugu	*Lannea edulis (Sond.)Engl.*	Anarcardiaceae	Food, medicinal
37	mpumba	*Alphoia theiformis (Vahl.)Benn.*	Flocaurtiaceae	Firewood
38	mduma	*Garcinia buchananii Bak.*	Clusiaceae	Medicinal. firewood
39	kilemandembwe	*Combretum collinum*	Combretaceae	Fuelwood
40	kihanza	*Strychnos spinosa*	Logniaceae	Food, medicine and timber
41	mtude	*Podocarpus sp*	Podocarpaceae	Medicinal
42	Mkaanga	*Cussonia sp.*	Araliaceae	Medicinal, firewood
43	Mteresi	*Premna holstii Gurke*	Lamiaceae	Food, firewood
44	Mtoosi	*Maerua triphylla A.*	Capparaceae	Food, medicine and timber
45	Munyowa	*Strychnos innocua*	Loganiaceae	Fruits, medicine
46	Mvembadanda	*Xeroderris stuhlmannii*	Fabaceae	Medicine
47	Mgiha	*Dalbergia arbutifolia*	Fabaceae subfamily Papilionoideae	Medicine, firewood
48	Mwembepori	*Ozoroa insignis*	Anacardiaceae	Fruits
49	Mkuyu	*Ficus sycomorus*	Moraceae	Food, medicine and timber
50	Msagala	*Burkea africana Hook*	Fabaceae	Firewood
51	Mkongolo	*Commiphora ugogensis*	Burseraceae	Food, medicine and timber
52	Mnyali	*Tamarindus indica*	Fabaceae	Fuel wood
53	Muvelevele	*Rauvolfia caffra*	Apocynaceae	Food, medicine and timber
54	Mtangadasi	*Strychnos spinosa*	Loganiceae	Fruits and medicine
55	Mfumbi	*Kigelia africana*	Bignoniaceae	Fruit
56	Mhanza	*Dalbergia nitidula*	Fabaceae	Firewood, medicinal
57	Msambalu	*Vangueria infausta Burch.*	Rubiaceae	Firewood, medicinal
58	Mkole	*Grewia fallax*	Fabaceae	Fruits, firewood
59	Mpalapanda	*Strychnos potatorum*	Loganiaceae	Firewood, medicinal
60	Mvelevele	*Vernonia amygdalina*	Astelaceae	Firewood, medicinal
61	Mlandala	*Combretum collinum*	Combretaceae	Fuel wood, medicinal
62	Mgulumo	*Lamea schweinfurthii*	Anacardiaceae	Fuel wood
63	Myombo	*Brachystegia boehmii*	Fabaceae	Fuel wood
64	Mlyasenga	*Combretum zeyheri*	Combretaceae	Firewood, medicinal
65	Mninga	*Pterocarpus angolensis*	Fabaceae	Timber and firewood
66	Mdeke	*Hymenodictyon parvifolium Oliv*	Rubiaceae	Timber, medicinal
67	Mgiha	*Dalbergia arbutifolia*	Fabaceae	Fuel wood
68	Kivanga	*Zanha africana*	Sapindaceae	Firewood, medicinal
69	Mwahama	*Shrebera trichoclada*	Oleaceae	Firewood, medicinal
70	Mkumbivawe	*Bauhinia petersiana*	Fabaceae	Medicinal

Code	Local (Hehe)	Scientific	Family	Uses
71	Mnyuwenyuwe	*Balbergia boehmii*	Fabaceae	Fuel wood , timber
72	Mtono	*Commiphora africana*	Burseraceae	Medicinal
73	Mkunungu	*Zanthoxylum chalybeum*	Rutaceae	Medicinal, food
74	Msagala	*Burkea africana Hook.*	Fabaceae	Fuel wood
75	Mgusi	*Brachystegia manga*	Fabaceae	Food and medicine
76	Mvembadanda	*Xeroderris stuhlmannii*	Fabaceae	Medicine
77	Msasamlo	*Psychotria schummaniana*	Rubiceae	Food and medicine
78	Mkambale	*Acacia mellifera*	Fabaceae	Fuel wood
79	Mkala	*Albizia petersiana*	Fabaceae	Firewood, medicinal
80	Mguhu	*Ximenia americana*	Olacaceae	Food and medicine
81	Kitimbwi	*Ormocarpum kirkii*	Fabaceae	Firewood
82	Mpelembe	*Adansonia digitata*	Bombaceae	Medicine
83	Msisina	*Albbizia harveyi Fourn*	Mimosaceae	Firewood
84	Mgeleke	*Dichrostachys cinerea (L.)*	Rubiaceae	Firewood
85	Mnyaluhanga	*Bridelia scleroneura*	Euphpbiaceae	Fuel wood and Medicine
86	Mgombani	*Combretum aculeatum*	Combretaceae	Firewood, medicinal
87	Mtundwa	*Ximenia caffra*	Olacaceae	Food and medicine
88	Mlandala	*Combretum collinum*	Combretaceae	Firewood
89	Mkunika	*Gardenia jovistonantis*	Rubiaceae	Medicine
90	Msumila	*Grewia forbessii*	Tiliaceae	Firewood
91	Mhuravega	*Albizia amara*	Fabaceae	Medicine
92	Mmemenamembe	*Marganitaria discoidea (bail.)*	Euphorbiaceae	Medicinal, firewood
93	Mkumbivao	*Bauhinia petersiana*	Fabaceae	Fire wood
94	Mbwejele	*Dichrostachys cinerea*	Fabaceae	Fuel wood
95	Mpogolo	*Catunaregam spinosa*	Rubiaceae	Medicinal, firewood
96	Mbungo	*Trilepesium madagacarensis D.C*	Moraceae	Medicine
97	Mkola	*Afzelia quanzensis*	Fabaceae	Fuel wood, medicine
98	Mtanganengo	*Ziziphus mucronata*	Rhamnaceae	Firewood
99	Mfilafila	*Diplorynchus candylocarpon*	Apocynaceae	Medicinal, fuel wood
100	Mningamaji	*Ptecarpus tinctorius*	Fabaceae	Timber, medicine
101	Mbwiru	*Friesodielsia lanciflora*	Burseraceae	Medicinal
102	Mwotaponzi	*Ozoroa insigns spp*	Anacardiaceae	Medicinal
103	Mlimbo	*Euphorbia cuneata. Vlh.*	Euphorbiaceae	Medicinal
104	Mtumbatumba	*Opilia amentaceae*	Opiliaceae	Medine, firewood
105	Mnywaugimbi	*Burkea africana Hook*	Fabaceae	Food and medicine
106	Mbumila	*Cassipourea mollis (R.Efr.) Alstom*	Rhizophorbiaeceae	Medicinal
107	Mtengwe	*Senna abbreviata*	Fabaceae	Firewood
108	Mkambalu	*Acacia mellifera*	Mimosaceae	Fuelwood

Code	**Local (Hehe)**	**Scientific**	**Family**	**Uses**
109	Chambi	*Cordia sinensis*	Boraginaceae	Medicinal
110	Mdaha	*Euclea usambarensis*	Ebenaceae	Medicinal
111	Mparapande	*Strychnos potatorum*	Loganiaceae	Medicine, firewood
112	Mnusa	*Combretum Zeyheri*	Comretaceae	Firewood, Medicine
113	Mtowo	*Azanza garckeana*	Bignoniaceae	Fruits, fuel wood
114	Mtangadasi	*Cissus cornifolia*	Vitaceae	Food and medicine
115	Mterela	*Brachystegia bussei Harms*	Fabaceae	Fuelwood
116	Mlandara	*Canthium pseudoverticillatum*	Rubiaceae	Medicine
117	Mhahama	*Shrebera trichoclada*	Oleaceae	Firewood, medicinal
118	Mhehevu	*Allophylus ferrugineus Taub.*	Sapindaceae	Firewood, medicinal
119	Mpolipoli	*Acacia drepanolobium*	Mimosaceae	Firewood, medicinal
120	Mchumaperu	*Flueggea virosa*	Euphorbiaceae	Medicine
121	Mkanyatowo	*Dombeya rotundifolia*	Rubiaceae	Medicinal, fuelwood
122	Mwotaponzi	*Ozoroa insigns ssp. reticulata*	Anacardiaceae	Firewood, medicinal
123	Mpunura	*Vites payos*	Lamiaceae	Firewood, medicinal
124	Mkongoro	*Commiphora ugogensis*	Burseraceae	Firewood, medicinal
125	Mpalapanda	*Strychnos potatorum*	Loganiaceae	Firewood, medicinal
126	Mbumira	*Cassipourea mollis*	Rhizophoraceae	Timber, medicinal, firewood
127	Msilalutumbu	*Excoecaeria bussei*	Euphorbiaceae	Medicine
128	Mhehefu	*Rhus natalensis*	Anacardiaceae	Food, medicinal, fuel wood
129	Mkungu	*Acacia sp*	Mimosaceae	Fuel wood
130	Mguvani	*Markhamia obtusifolia*	Bignoniaceae	Medicine
131	Motaponzi	*Ozoroa reticulata*	Anacardiaceae	Firewood, medicine
132	Mfumbi	*Kigelia africana*	Bignoniaceae	Timber, fuelwood
133	Mhuragavega	*Albizia amara (Roxb.)*	Mimosaceae	Medicine, firewood
134	Mbwegele	*Sclerocarya birrea*	Fabaceae	Firewood
135	Mgusi	*Brachystegia manga*	Caesalpiniaceae	Medicine, firewood
136	Mdavi	*Cordia sinensis lam.*	Boraginaceae	Food and medicine
137	Mdungwa	*Kigelia africana*	Bignoniaceae	Medicine
138	Mkelenge	*Terminalia mollis*	Combretaceae	Firewood
139	Mzima	*Terminalia sericea*	Combretaceae	Firewood, medicinal

Appendix 2: Some additional and corrections made for key figures and statistics in the published papers



Stocking and regeneration pattern in CBFM forests

Comparison of stocking parameters in forest resource based on management practiced

Forest name	District	Management	N(ha^{-1})	G(m^2/ha^{-1})	V(m^{3}ha^{-1})
Mandumburu	Mufindi	CBFM (n=52)	2716±2169	9.01±2.81	1.63±1.17
Ngombe	Mufindi	BAU (n=40)	3216±2254	10.71±4.84	1.86±1.30
Kingegenyanyembe	Mufindi	CBFM (n=30	4118 ± 2811	10.59 ± 5.37	1.76 ± 1.11
Kingegenyanyembe	Mufindii	BAU (n=30)	2522 ± 1636	5.14 ± 3.09	0.49 ± 0.66
Gangalamtumba	Iringa rural	CBFM (n=30)	1982±1563	11.56±3.69	4.51±2.42
Kidundakiyave	Iringa rural	CBFM (n=32)	2655±2207	9.07±2.88	1.85±1.48
Makota	Iringa rural	BAU (n=30)	2237±2119	8.45±3.98	1.23±0.71

Note: N is the number of stems ha^{-1}, G is the basal area (m^{2}ha^{-1}) and V is the volume (m^{3}ha^{-1}), number after ± are 95% confidence limits (products of standard errors of the mean and t-value at 95% confidence level

Land use and miombo cover change before and after CBFM, Gangalamtumba

Land use type	2000 (before)		2013 (after)		2000 - 2013		2000 - 2013
	Cover area (ha)	Cover coverage (%)	Cover area (ha)	Cover coverage (%)	Cover Change area (ha)	Cover Change (%)	Annual rate of change (ha/year)
Closed woodland	431.01	7.1	594.54	9.7	163.53	2.6	12.6
Open woodland	4439.43	72.4	3933.27	-64.2	-506.16	-8.2	-38.9
Bushed grassland	1054.8	17.2	1417.32	23.1	362.52	5.9	27.9
Cultivated lands	136.26	2.2	107.01	-1.8	-29.25	-0.4	-2.3
Unclassified land	66.6	1.1	75.96	1.2	9.36	0.1	0.7
Total	**6128.1**	**100**	**6128.1**	**100**			

Land use and miombo cover change before and after CBFM, Kidundakiyave

Land use type	**2000 (before)**		**2013 (after)**		**2000 - 2013**		**2000 - 2013**
	Cover area (ha)	**Cover coverage (%)**	**Cover area (ha)**	**Cover coverage (%)**	**Cover Change area (ha)**	**Cove Change (%)**	**Annual rate of change (ha/year)**
Closed woodland	598.32	11.8	754.29	14.8	155.97	3	12
Open woodland	2682.36	52.8	3101.67	61	419.31	8.2	32.3
Bushed grassland	1496.34	29.4	1057.05	20.8	-439.29	-8.6	-33.8
Cultivated lands	144.45	2.8	103.14	2	-41.31	-0.8	-3.2
Unclassified land	163.62	3.2	68.94	1.4	-94.68	-1.8	-7.3
Total	**5085.09**	**100**	**5085.09**	**100**			

Land use and miombo cover change before and after CBFM in Mandumburu

Land use type	**2000 (before)**		**2013 (after)**		**2000 - 2013**		**2000 - 2013**
	Cover area (ha)	**Coverage (%)**	**Cover area (ha)**	**Coverage (%)**	**Change area (ha)**	**Change (%)**	**Rate of change (ha/year)**
Closed woodland	85.05	35.99	98.95	41.87	13.9	16.34	1.07
Open woodland	90.36	38.24	84.38	35.71	-5.98	-6.62	-0.46
Bushed grassland	20.52	8.68	18.85	7.98	-1.67	-8.14	-0.13
Cultivated lands	17.08	7.23	19.08	8.07	2.00	11.71	0.15
Unclassified land	23.31	9.86	15.06	6.37	-8.25	-35.39	-0.63
Total	**236.32**	**100**	**236.32**	**100**			

Factors for land use and miombo woodlands cover change as perceived by local communities

Underlying factors	**Respondents perception from different study sites**				
	Gangalamtumba (n=64)	Kidundakiyave (n= 48)	Mandumburu (n= 46	Kingegenyanyembe (n= 60)	Overall score (n=218)
Charcoal production	56	40	38	44	178
Fire wood extraction	47	41	36	51	175
Livestock grazing	28	36	41	47	152
Cultivated fields	21	16	34	18	89
Construction materials	23	18	25	17	83
Forest fires	12	9	19	20	60
Plantation establishments	22	15	14	9	60
Encroachments	7	15	9	21	52
Human population	11	13	6	15	45
Others	5	9	12	8	34

Activities and stump density indicating extraction level in miombo woodlands

Associated cause of extraction	Stump density (N/ha)	Proportion (%)
Charcoal making	234 ±56	50
Fire wood	107 ± 31	22.86
Poles	73 ± 29	15.60
Timber	54 ± 17	11.54
Overall	468 ± 103	100

Extent of woodland extraction before and after CBFM based on stumps (n=120)

Periods	Density (N/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	Biomass (t/ha)	Carbon stock (t/ha)
New stumps	137±12	1.78±2.31	9.63±2.35	7.89±0.3	3.95±0.41
Old stumps	331± 29	4.69±2.72	15.41±3.09	13.77±0.8	6.88±0.62
Overall	468±23	6.47±5.08	25.04±5.44	21.66±1.04	10.83±1.03

Comparison of biomass and carbon stock in CBFM and BAU study sites

Forest name	Management	AGB (t/ ha^{-1})	CO$_2$ eq (t/ha^{-1})	BGB(t/ha)	CO$_2$eq (t/ha^{-1})	Total CO$_2$(t/ha)
Mandumburu	PFM	1.10 ± 0.80	2.01 ± 1.46	0.54±0.30	0.99±0.54	3.00±2.00 a
Ngombe	BAU	1.25 ±0.88	2.30 ± 1.62	0.62±0.36	1.13±0.66	3.43±2.28 a
Kingegenyanyembe	CBFM	1.21 ± 0.74	2.22 ± 1.36	0.61±0.28	1.11±0.51	3.33±1.87 a
Kingegenyanyembe	BAU	0.33 ± 0.45	0.60 ± 0.82	0.19±0.22	0.35±0.40	0.95±1.22 b
Gangalamtumba	CBFM	3.06±1.65	5.61±3.02	1.29±0.61	2.36±1.11	7.97±4.13 ab
Makota	BAU	0.83±0.48	1.52±0.89	0.43±0.23	0.78±0.42	2.30±1.31 b
Kidundakiyavye	CBFM	1.25 ± 1.01	2.29 ± 1.85	0.61±0.37	1.10±0.68	3.39±2.53 a
Makota	BAU	0.83±0.48	1.52±0.89	0.43±0.23	0.78±0.42	2.30±1.31 b

Note: Number after ± are 95% confidence limits (products of standard errors of the mean and t-value at 95% confidence level) and means with the same letter are not significantly different using Bonferoni t-test (α= 0.05)

Extent of woodland extraction in CBFM and BAU based on stumps (n=244)

Management practice	Density (N/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	Biomass (t/ha)	Carbon stock (t/ha)
In CBFM	167± 24	5.31 ± 2.78	9.63±2.35	7.89±0.3	3.95 ± 0.41
In BAU	431± 49	8.29± 3.32	15.41±5.09	13.77±0.8	6.88 ± 0.62
Overall	598±73	13.60±6.10	25.04±7.44	21.66±1.10	10.83 ± 1.03

Note: N is the number of stems ha^{-1}, G is the basal area (m^{2}ha^{-1}) and V is the volume (m^{3}ha^{-1}), number after ± are 95% confidence limits (products of standard errors of the mean and t-value at 95% confidence level

Annual potential value from improved carbon stock if sold at 5USD /tCO$_2$e in voluntary market

Study site	Forest area (ha)	Change in carbon stock (t/ha/yr)	CO$_2$e (t/ha/yr)	Potential annual income ($/ha/yr)	Annual value for whole forest area ($)
Kingegenyanyembe	459.6	0.88	3.23	16.15	7422.54
Gangalamtumba	6,065	2.23	8.18	40.9	248,058.50
Kidundakiyave	4904	0.42	1.54	7.70	37760.80
Mandumburu	450	0.15	0.55	2.75	1237.50

However, offsets that deliver complementary benefits such as biodiversity conservation and poverty reduction are likely to command a premium (Bayon, *et al.*, 2007).

Estimated costs and net benefit of improved carbon stock in voluntary market

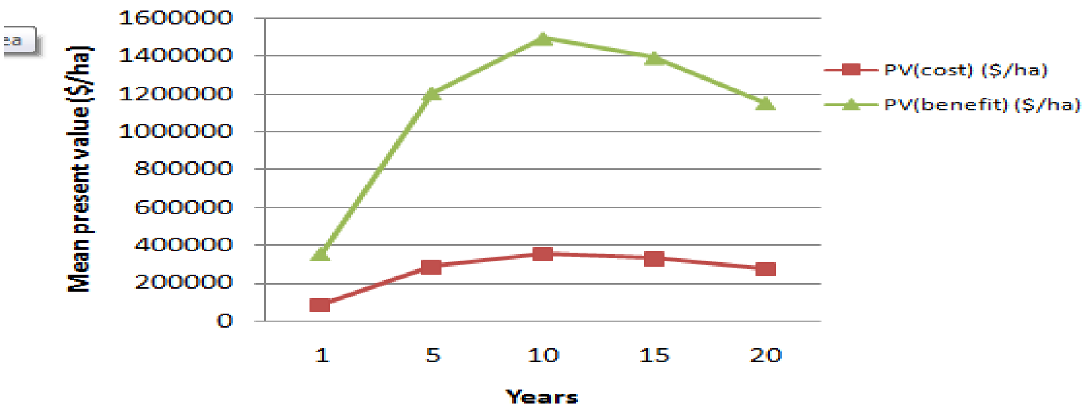
Study site	Management cost ($/yr)	Opportunity cost ($/yr)	Transaction cost ($/yr)	Total annual cost ($)	Value of improved carbon stock ($/yr)	Net benefit from improved carbon stock ($/yr)
Kingegenyanyembe	1 580	2 389.92	919.2	4 889.12	7422.54	2533.42
Gangalamtumba	1 580	31 538	12 130	45 248	248,058.50	202,810.50
Kidundakiyave	1580	25 500.8	9808	36888.8	37760.80	872.00
Mandumburu	1 580	2 340	900	4 820	1237.50	6057.5

Estimated cost and benefits of improved carbon stock in CBFM and its economic feasibility

Year	Cost ($/ha)	Benefit ($/ha)	Discount factor	PV(cost) ($/ha)	PV(benefit) ($/ha)	NPV ($/ha)	IRR ($/ha/yr) r	722216
1	22961.48	73001.09	0.91	20874	66365	45491	0.05	1289130
5	114807.4	365005.45	0.62	71286	226640	155353	0.1	722216
10	229614.8	730010.9	0.39	88526	281451	192924	0.15	444988
15	344422.2	1095016.4	0.24	82452	262138	179686	0.2	297888
20	459229.6	1460021.8	0.15	68262	217023	148761	0.25	213694
			Total	331400	1053616	722216	0.3	162105
				Benefit-cost ratio	3.18		0.5	77000

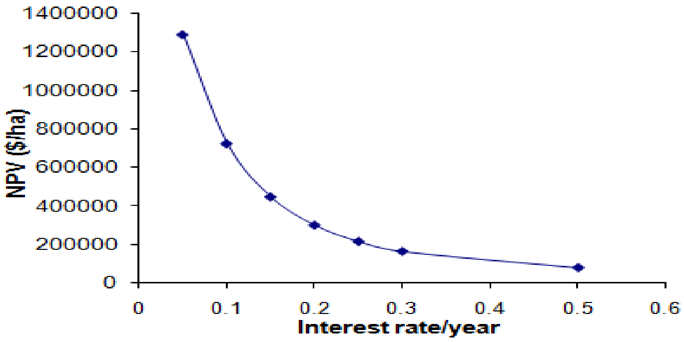
Note: Interest rate used for present value is 10% and Internal rate of return (IRR) at various interests (r)

Projected mean present value of costs and benefits



This analysis shows that net present value for improved carbon stock if sold in emerging voluntary carbon market are likely to deliver greater benefits at a lower cost than if the carbon market is ignored.

NPV of carbon stock with varying interest rate as carbon project



The NPV of carbon stock value at various interest rates

NPV decreases as interest rate increases, implies the important of short term contract. This suggests that there is a need for policy-makers to clearly define crediting period and interest rate while targeting CBFM interventions.