The Economics of Climate Change Vulnerability, Adaptation and Mitigation in Tanzania

By

Coretha Komba

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Supervisor: Associate Professor Edwin Muchapondwa

Plagiarism Declaration

This thesis is my original work. Where other people's work is used this is acknowledged. I declare that it has not been previously submitted for the award of a degree at any university.

Candidate: Coretha Komba

Date: 24 November 2014

Preface

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List of Acronyms

3AR	Third Assessment Report
ASDP	Agricultural Sector Development Programme
ASDS	Agricultural Sector Development Strategy
BLUE	Best Linear Unbiased Estimator
CBFM	Community-Based Forest Management
CO_2	Carbon Dioxide
COP	Conference of the Parties
CV	Contingent Valuation
FAO	Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FGLS	Feasible Generalised Least Square
FRA	Forest Resources Assessment
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IIA	Independence from Irrelevant Alternatives
IMR	Inverse Mills Ratio
IPCC	Intergovernmental Panel on Climate Change
MAFC	Ministry of Agriculture, Food Security and Cooperatives
MIP	Most Important forest Products
MJUMITA	Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania
MKUKUTA	Mkakati wa Kukuza Uchumi na Kupunguza Umaskini
MNL	MultiNomial Logit
MNP	Multinomial Probit
NAPA	National Adaptation Programme of Action
NBS	National Bureau of Statistics
NGOs	Non-Governmental Organisations
NSGRP	National Strategy for Growth and Reduction of Poverty
OLS	Ordinary Least Squares
PES	Payment for Environmental Services
PFM	Participatory Forest Management
RED	Reducing Emission from Deforestation
REDD	Reducing Emission from Deforestation and Forest Degradation

R-PIN	Readiness Plan Idea Note
SACOS	Savings and Credit Cooperative Society
SSA	Sub-Saharan Africa
tCO_2/ha	tonnes Carbon dioxide per hectare
TFCG	Tanzania Forest Conservation Group
TMA	Tanzania Meteorological Agency
TZS	Tanzanian Shillings
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations – Reducing Emission from Deforestation and Forest Degradation
URT	United Republic of Tanzania
USD	United States Dollar
VEP	Vulnerability as Expected Poverty
VICOBA	Village Community Banks
VIF	Variance Inflation Factor
VPL	Vulnerability Poverty Line
WTA	Willingness to Accept

Chapter 1: Introduction

1.1 Background to the study and statement of the problem

The term climate change here is defined as variation in the mean state of climate or its continuing, long term variability (IPCC, 2003). Climate variability consists of the statistics of temperature, rainfall, wind, humidity, atmospheric pressure, and other meteorological elemental measurements in a given region over long periods. This is unlike weather variability, which is the present condition of these elements and their variation over shorter periods. Climates can be classified according to the average and the typical ranges of different variables, most commonly precipitation and temperature (Trenberth et al., 2000). In this study, we use the term climate change to refer to any long term (i.e. 20 years)[1] variation in climate regardless of cause as put forward by IPCC (2003). Climate variability refers to;(i) change in rainfall seasons, that is, earlier or later rainfall seasons than usual; (ii) an increase or decrease in rainfall beyond what is expected; and (iii) an increase or decrease in temperature beyond what is expected (Huber and Gulledge, 2011).

Environmental scholars in their Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) reached a tentative consensus that climates are changing. Stern (2007) points out that these changes in climate will be more unreliable in the future. That is, it has been observed in recent years, that climate change is currently the greatest environmental, social and economic threat to the planet. In the last few years, scientific research and knowledge on climate change has progressed substantially, confirming that the current warming of the planet's climate is very likely due to human activities. For instance, regular burning of fossil fuels[2], deforestation and other changes in land-use result in an increase in emissions of greenhouse gases in the environment (Stern, 2007:4; Van Aalst, 2006). As a result of this unrestricted growth of greenhouse gases emissions the average annual global

[1] Many literature sources cite standard climate norms as 30 year averages of meteorological conditions such as temperature and rainfall (Argues, 2012). But for the purposes of this study, 20 years average is used because farmers were asked to recall what was happening during those years. 10 to 20 years is not a short period for the farmer to recall

[2] Fossil fuels is a general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the Earth's crust over hundreds of millions of years

temperature is rising and in some places the average annual precipitation is declining, leading to declines in agricultural productivity, especially in developing countries.

Globally, many sectors of economy are affected by climate change. In developing countries, agriculture has largely been the major victim of the negative impacts of variability[3] of temperature and rainfall. This is because the agricultural sector which is the dominant sector in most developing countries, especially in Sub-Saharan Africa (SSA) is rain-fed. It is reported that 95 percent of Africa's as well as Tanzania's agriculture is rain-fed (Hall, 2011; Hepworth, 2010). In recent years, unreliable rainfall (changes in variance and seasons of rainfall) has been observed. It is also noted that the global mean surface temperature is rising beyond what is expected by the atmospheric scientists and other stakeholders. Rising sea levels and other physical changes in climate are also apparent in different areas. Recently it has been common for some areas to receive rainfall that is not sufficient for crop production (drought), while other areas receive too much rainfall, which leads to floods. Some areas experience early or late seasons of rainfall which differ from the normal seasons. Both situations are not good for agricultural activities. The same applies to the forestry sector.

Most developing countries are vulnerable to climate variability. This is so because in these countries the agricultural sector still depends on climate/weather for crop production. Farmers in those countries must consider implementing adaptation[4] methods that can help them in reducing their vulnerability to climate variability. It is important to consider the role of mitigation[5] of climate change though this might be unfavourable to smallholder farmers if they have to implement mitigation strategies without support from government and other environmental stakeholders. The reasons for preferring adaptation over mitigation for developing countries have been well stated by Füssel and Klein (2006:304). For example, they point out that, unlike mitigation that requires international cooperation, adaptation can effectively be implemented on a local or regional scale. Thus the advantage of adaptation is that a farmer/country/region uses the opportunities provided by the climatic environment to reduce the negative effects without relying on other farmers/countries.

[4] According to Smit et al (2000) adaptation is a process whereby societies manage to reduce the negative effect of climate and take advantage of opportunities that their climatic environment provides.

[5] Mitigating climate change means putting a stop to activities that cause climate change, e.g. emission of greenhouse gases (GHG)

To come up with a policy that helps smallholder farmers' strategies towards adaptation to climate change, it is useful to first look at the factors explaining farmers' vulnerability[6] to these changes. The types of farmers that are more susceptible to climate change should be pointed out and their characteristics should be assessed. A thorough study of the farmers' vulnerability to climate change should be conducted. Once the issues underlying this vulnerability have been investigated, the study can suggest strategically effective adaptation methods which could have an impact on reducing farmers' vulnerability. Furthermore, it is very important for the countries in question not to ignore the importance of mitigation.

Developing countries are most vulnerable to climate variability because it is not easy for such countries to respond to climatic stimuli. Many farmers, especially smallholder farmers in developing countries, are poor and struggle to respond effectively to change. Watson et al (1998) noted that the vulnerable country's response to climate change is slow even though there is sensitivity[7] among policymakers. Most developing countries, especially SSA countries, are believed to be more vulnerable not because the climate variability in Africa is higher, but because most of the economies depend on rain-fed agricultural activities. It is known that even small climate variability is likely to impact more on crop harvests in such countries. This is because most SSA countries are located in tropical regions where the temperature is already high. When crops are at high levels of temperature tolerance, a small increase in temperature will adversely affect output. In line with temperature changes, variations in rainfall above or below the required amount lead to reduction in the output of crops. Early or late rainfall beyond the rainfall seasons familiar to farmers will also have a negative effect on crop production.

There are many studies which analysed the impacts of climate change and highlighted factors that have been found to matter in choosing adaptation methods in agricultural activities in Africa (Maddison, 2006; Seo and Mendelsohn, 2008; Hassan and Nhemachena, 2008).

Apart from the studies examining Africa as a whole, there are some studies analysing the factors influencing the choice of adaptation methods piloted in specific countries such as Benin, Ethiopia, Ghana, Kenya, Nigeria, South Africa, and Uganda, (see for example Bryan et al, 2009, 2013; Deresa et al, 2009; Hisali et al, 2011; Kabubo-Mariara, 2008; Mideksa, 2009;

[6] According to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001), vulnerability is the extent to which the adverse effects of climate change damage or harm a system

[7] Smit et al (2000) defined sensitivity as the degree whereby a society is either affected or responsive to climate stimuli

Tambo & Abdoulaye, 2013; Yalo, 2013; and Yegbemey et al, 2011). The need for conducting country specific studies of the impact of adaptation methods is that some factors that might be relevant to some countries might not necessarily matter or be viable in other countries. The choice and implementation of adaptation strategies in a certain country may depend on how vulnerable and sensitive a country is to climate variability. It may also depend on the accessibility of the adaptation used by the countries and/or areas in question (for example irrigation[8], water harvesting scheme, insurance etc.).

There are also numerous studies that point out that efforts to address climate change should focus on mitigation rather than adaptation (Kates, 2000; Kandlikar and Sagar, 1999; Lorenzoni et al, 2000; Sharma and Kumar, 1998). Mitigation strategies might be expensive for developing countries such as Tanzania to focus on without the support from developed countries. It is important to focus on both strategies especially now that developed countries are considering supporting (financially) mitigation by developing countries through various projects like REDD+[9]. In analysing the uncertain emission reductions from forest conservation, Watson et al (2013) found that estimated revenues provided by REDD+ projects have impacts on decisions concerning whether or not the forest communities participate in the programme. This also has an influence on the implications for the level of benefit sharing. There is a strong belief that if the financial incentives provided by REDD+ projects are strong enough, forest carbon stock estimates will be improved and the environmental integrity will be achieved (Watson et al. 2013). There may therefore be advantages for developing countries in participating in mitigation strategies.

This study contributes to the literature by analysing approaches to the choice of adaptation[10] methods[11] aimed at reducing the vulnerability of farmers to the impacts of climate change as well as investigating the willingness of households to participate in the REDD+ program in Tanzania. Tanzanian farmers, just like farmers in other SSA countries, face climate change

[8] Some farming takes place very far from rivers, lakes and other water bodies, in this case irrigation is not possible

[9] According to Herold et al (2011) the + sign means the project includes reducing deforestation and forest degradation, enhancing and conserving forest carbon stocks, and sustainable management of forests.

[10] This paper adopts Schipper's (2007:8) "Adaptation Approach" to development in which the society carries out adaptation so as to respond to the observed and experienced impacts of climate change (**Adaptation to climate change impacts → Vulnerability reduction → Development**)

[11] Most of the previously mentioned studies identify the use of crop varieties, planting trees, soil conservation, changing planting dates, and irrigation to be the most utilised adaptation strategies in Ethiopia, South Africa and Kenya

challenges. The farmers are expected to cushion themselves from the negative impacts of these changes. The biggest challenge Tanzania faces is to reduce the severity of impact through adaptation and to halt further changes through mitigation.

Achieving substantial improvements in adaptation and mitigation will assist the international policy initiatives aimed at the reduction of the negative impacts of climate change. Both strategies are important for the Tanzanian economy through their contribution to the agricultural sector which is the backbone of the economy. Apart from being important for the Tanzanian economy, the strategies are important for meeting the Millennium Development Goals of poverty and hunger reduction as well as stabilizing greenhouse gases on the planet. Although there are some studies on the impacts of climate change on Tanzania, this study focuses on the specific impacts on farm households. There is a need to determine how individual farmers are vulnerable and to confirm the characteristics of individual farmers who are highly vulnerable. There is also a need to identify the factors that influence the willingness of individual households to accept participation in the REDD+ program.

1.2 The Tanzanian Economy

In 2011 and 2012, Tanzania's economy grew at a rate of more than 6 percent, indicating resilience to the world economic crisis (Morisset, 2012). This increase is partly due to an increase in agricultural productivity which in 2012 increased by 4.7 percent compared to 3.5 percent in 2011 (NSB, 2012). It has been pointed out that Tanzania also substantially decreased its fiscal deficit. Regardless of some volatility at the end of 2011, the nation's financial indicators are now generally suggestive of good economic performance. Tanzania's inflation rate is the only macro-economic indicator that is performing badly. According to the National Bureau of Statistics of Tanzania, in 2011 and 2012 the Tanzania's annual average inflation rate was 12.6 and 16 percent respectively (NBS, 2012). Given the current world context, Tanzania's economic performance is commendable.

1.2.1 Tanzania's Agriculture Sector, Agro-ecological Zones and Climate Change

Like other countries in Sub-Saharan Africa (SSA), the agriculture sector plays an important role in the economic development of Tanzania. About 80 percent of the Tanzanian population live in rural areas and their livelihoods depend upon agriculture (Andersson et al, 2005; Kwa, 2001). At the national level, the agriculture sector contributes a significant share to the Gross Domestic Product (GDP) and generates a significant amount of the nations' foreign exchange earnings. While the agriculture sector's share in the country's GDP was 49 percent in 1970, this share was 46 percent in 2002 and 26.5 percent in 2007 (MAFC, 2008)[12]. Although the figures show a decreasing trend, the contribution of agriculture to GDP is still significant. For the rural population and the country in general, sustainable agricultural production offers the way to improve welfare through reduction of poverty and improvement in food security. Therefore, initiatives geared towards agricultural sector development are critical to the livelihoods of many Tanzanian rural communities. Given the large proportion of farmers in Tanzania mostly depending on rainfall which is currently affected by climate change, there is a need for the farmers to cushion themselves. Adaptation is important in order to reduce the negative impacts because the agricultural output will increase and as a result, food security will improve.

According to United Republic of Tanzania (2005), Tanzania has about 88.6 million hectares of land suitable for agriculture, including 60 million hectares of rangelands suitable for livestock grazing. However part of this land is only marginally suitable for agricultural production and livestock grazing because of problems with drought and tsetse fly infestation. In 2002, only 23 percent of the arable land in Tanzania was under cultivation, and of that about 97 percent was rain-fed. This despite the fact that in 2011, 42.1 percent of Tanzanian land area was listed as suitable for agriculture and livestock keeping (Vice President's Office, 2012). Apart from having a huge area of unutilised land, it has also been identified that the majority of players in agriculture are smallholder subsistence farmers. According to Lugoe (2010), almost 85 percent of the land which is suitable for agriculture is used by smallholder farmers and traditional agro-pastoralists. It is estimated that on average the farmers farm on land of between 0.12 and 2 hectares (Government of Tanzania, 1999).

In addition, about 70 percent of Tanzania's crop area is cultivated using hand hoes, 20 percent by ox plough and only 10 percent by tractor. According to Kawa and Kaitira (2007), the major subsistence crops cultivated by subsistence farmers in Tanzania are maize, rice, sorghum, millet, beans, cassava, bananas, and vegetables. They mention that most farmers rely on rainfall to support their agricultural activities and it has been recognised in recent years that rainfall is inadequate and unevenly distributed. This has resulted in those few farmers who can afford it resorting to irrigation. In support, the Tanzania government has been emphasizing to the smallholder farmers the necessity of increasing productivity in

[12] The significant decrease in the agricultural share to the GDP in those years was due to increase in active roles in other sectors such as mining, tourism and service sectors (MAFC, 2008)

agriculture so as to achieve the 6-8 percent annual growth rate targeted in the National Strategy for growth and reduction of poverty (Vice President's Office, 2005) and providing them with technical support from the agricultural officers. Tanzania resolves to accelerate these agricultural transformations through its well-known "Kilimo Kwanza" policy. This policy is a Tanzanian national determination to speed up agricultural transformation. It enhances the implementation of the Agricultural Sector Development Programme (ASDP) and accelerates implementation and achievement of Millennium Development Goals (MDGs). A strong emphasis of Kilimo Kwanza is pro-poor growth. The policy provides national coordination of resources, planning and accountability for implementation of agricultural transformation. Moreover, Tanzania prepared a National Adaptation Programmes of Actions (NAPA) in 2007 in order to identify the immediate short-term priorities required by the United Nations Framework Convention on Climate Change (UNFCCC). However, the NAPA did not accommodate the activities that are related to climate knowledge and forecasting and capacity building (Hepworth, 2010).

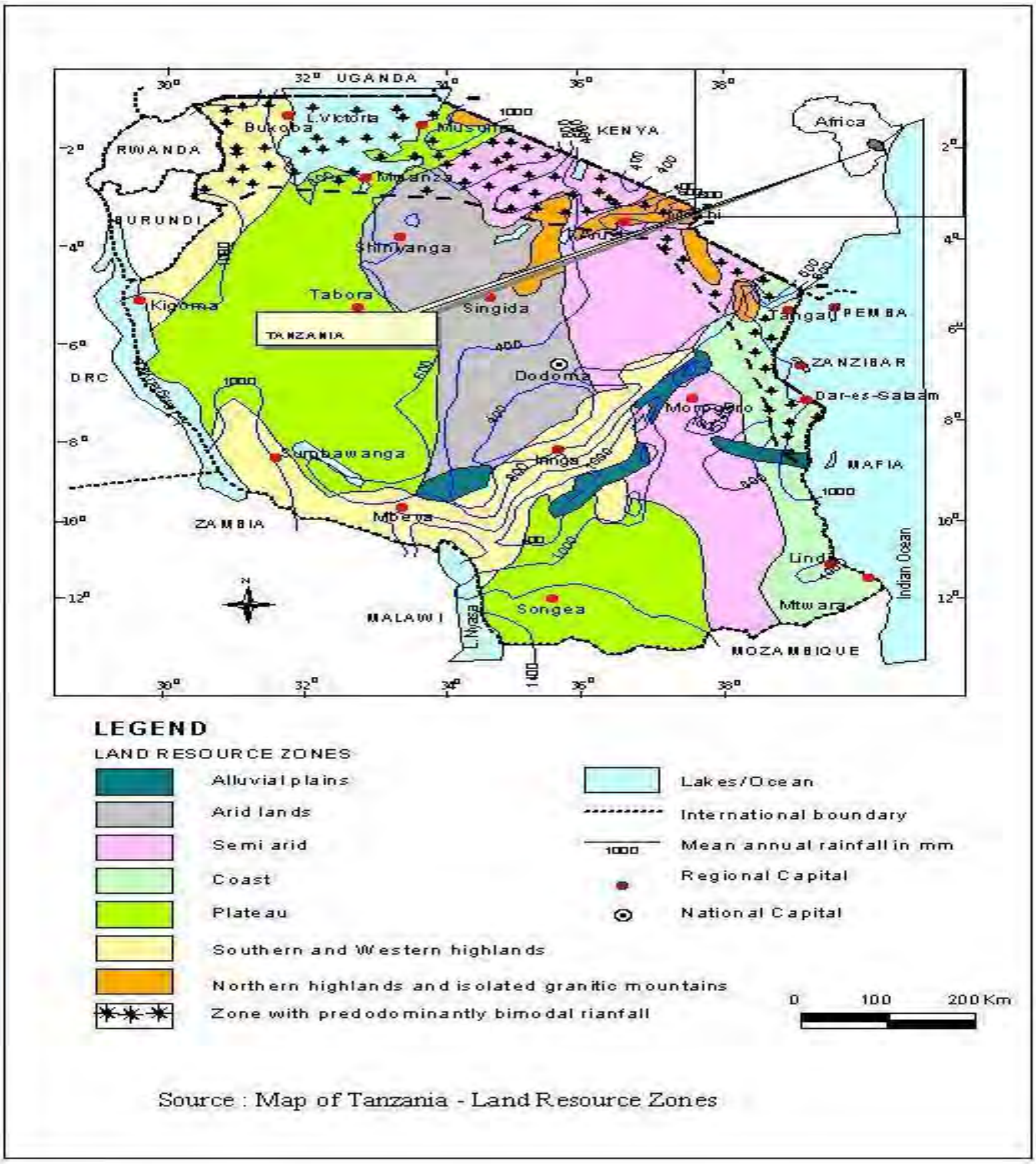
Tanzania has seven main agro-ecological zones. The categorization of agro-ecological zones is based on sub-zone and areas, soil and topography, altitude, average annual rainfall pattern, and dependable growing seasons (see Table 1.1 and Figure 1.1). The agro-ecological zones are Coastal; Arid lands; Semi-arid lands; Plateaux; Southern and Western highlands; Northern highlands; and Alluvial plains. This study took place in seven administrative regions of Tanzania (Tanga, Coast, Iringa, Dodoma, Shinyanga, Morogoro, and Lindi). These areas represent six out of the seven agro-ecological zones. The diversification of the area of the study is deliberate in order to get a good proxy for climate change so that the results obtained from the study can be generalized to the rest of the country.

Table 1.1: Tanzania's Agro-ecological zones

Zone	Sub-Zone and areas	Soils and Topography	Altitude	Rainfall (mm/yr)	Growing season
COASTAL	**North:** Tanga (except Lushoto), Coast and Dar-es-Salaam **South:** Eastern Lindi and Mtwara (except Makonde Plateau	-Infertile sands on gently rolling uplands -Alluvial soils in Rufuji -Sand and infertile soils -Fertile clays on uplands and river flood plains	Under 3000m	**North:** Bimodal, 750-1200mm **South**: Unimodal, 800-1200mm	**North:** Oct-Dec and March-June **South:** Dec-April
ARID LANDS	**North:** Serengeti, Ngorogoro Parks, Part of Masailand Masai Steppe, Tarangire Park, Mkomazi Reserve, Pangani and Eastern Dodoma	**North:** Volcanic ash and sediments. Soils variable in texture and very susceptible to water erosion **South:** Rolling plains of low fertility. Susceptible to water erosion. Pangani river flood plain with saline, alkaline soil	**North:** 1300-1800m **South** 500-1500m	**North:** Unimodal, unreliable, 500-600mm **South:** Unimodal and Unreliable, 400-600mm	March- May
SEMI-ARID LANDS	Central Dodoma, Singida, Northern Iringa, some of Arusha, Shinyanga **Southern:** Morogoro (except Kiliombero and Wami Basins and Uluguru Mts). Also Lindi and Southwest Mtwara	**Central:** Undulating plains with rocky hills and low scarps. Well drained soils with low fertility. Alluvial hardpan and saline soils in Eastern Rift Valley and lake Eyasi. Black cracking soils in Shinyanga. **Southern:** Flat or undulating plains with rocky hills, moderate fertile loams and clays in South (Morogoro), infertile sand soils in centre	**Central:** 1000- 1500m **S/eastern**: 200-600m	**Central:** unimodal and unreliable: 500-800mm **S/eastern:** Unimodal 600-800m	Dec - March
PLATEAUX	**Western:** Tabora, Rukwa (North and Center), Mbeya **North:** Kigoma, Part of Mara	**Western:** Wide sandy plains and Rift Valley scarps Flooded swamps of Malagarasi and Ugalla rivers have clay soil with high fertility **Southern:** upland plains with rock hills. Clay soils of low to moderate fertility in south, infertile sands in North.	800-1500m	**Western:** unimodal, 800-1000mm **Southern:** unimodal, very reliable, 900-1300mm	Nov- April

Zone	Sub-Zone and areas	Soils and Topography	Altitude	Rainfall (mm/yr)	Growing season
	Southern: Ruvuma and Southern Morogoro				
SOUTHERN AND WESTERN HIGHLANDS	**Southern:** A broad ridge of from N. Morogoro to N. Lake Nyasa, covering part of Iringa, Mbeya **Southwestern:** Ufipa plateau in Sumbawanga **Western:** Along the shore of Lake Tanganyika in Kigoma and Kagera	**Southern:** Undulating plains to dissected hills and mountains. Moderately fertile clay soils with volcanic soils in Mbeya **S/western:** Undulating plateau above Rift Valleys and sand soils of low fertility **Western:** North-south ridges separated by swampy valleys, loam and clay soils of low fertility in hills, with alluvium and ponded clays in the valleys	**Southern:** 1200-1500m **S/western** 1400-2300m **Western:** 100-1800m	**Southern:** unimodal, reliable, local rain shadows, 800-1400mm **Southern:** unimodal, reliable, 800-1000mm **Western:** bimodal, 1000-2000mm	**Northern:** Dec–April **S/western:** Nov- April **Western:** Oct-Dec and Febr-May
NORTHERN HIGHLANDS	**Northern:** foot of mt Kilimanjaro and Mt. Meru. Eastern Rift Valley to Eyasi **Granite Mts:** Uluguru in Morogoro, Pare Mts in Kilimanjaro and Usambara Mts in Tanga, Tarime highlands in Mara	**Northern:** Volcanic uplands, volcanic soils from lavas and ash. Deep fertile loams. Soils in dry areas prone to water erosion. Granite steep Mountain side to highland plateaux. Soils are deep, arable and moderately fertile on upper slopes, shallow and stony on steep slopes	**Northern:** 1000-2500m **Granitic mts:** 1000-2000m	**Northern:** Bimodal, varies widely 1000-2000mm **Granitic mts.** Bimodal and very reliable 1000- 2000mm	**Northern:** Nov-Jan and March-June **Granitic Mts.** Oct-Dec and March-June
ALLUVIAL PLAINS	K-Kilombero (Morogoro) R- Rufuji (Coast) U- Usangu (Mbeya) W- Wami(Morogoro)	K-Central clay plain with alluvial fans east and west R- Wide mangrove swamp delta, alluvial soils, sandy upstream, loamy down steam in floodplain U-Seasonally Flooded clay soils in North, alluvial fans in South W- Moderately alkaline black soils in East, alluvial fans with well drained black loam in West		K—Unimodal, very reliable, 900-1300mm R-Unimodal, often Inadequate 800-1200mm U-Unimodal, 500-800mm W-Unimodal, 600-1800mm	K-Nov-April R- Dec-April U-Dec-March W-Dec-March

Source: *adopted from United Republic of Tanzania (2007)*



Source: *adopted from Shayo (2007)*

Figure 1.1: Tanzania's Agro-ecological zones: Map

1.3 Research Objectives

The government of Tanzania aims to transform small and medium scale farmers into commercial entities through the well-known "Kilimo Kwanza" policy regardless of climate change. This study provides useful information to the government by analysing the groups that are vulnerable and provides recommendations for the policy makers in order that they may advise farmers on the best practices regarding adaptation and mitigation. The main objective of this study is therefore to provide empirical evidence to help smallholder farmers reduce the severity of their vulnerability to already occurring changes to the climate through effective adaptation. It also aims to inform efforts to bring to an end further change in climate through mitigation. Specific objectives of the study are:

1) To identify the characteristics of farmers who are vulnerable to climate change in Tanzania and assess the potential role of effective adaptation methods in reducing their vulnerability.
2) Examine the factors influencing the farmers' choice of adaptation methods.
3) Analyse the factors affecting Tanzanian household participation in the United Nations Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation (REDD+)

1.4 Proposed Structure

The study consists of Six Chapters.

Chapter One has served as an introduction to the study. This includes the background to the study and the issues to be addressed by the study. These include deforestation, forest degradation and REDD+ status in Tanzania's agriculture sector and agro-ecological zones.

Chapter Two presents the history of climate change and looks at what other researchers have found in their studies on farmers' perceptions of climate change, farmers' vulnerability to climate change and farmers' adaptation to and mitigation of climate change.

Chapter Three assesses the prospects of farmers experiencing poverty in the future due to climate change. It examines the characteristics of vulnerable farmers, and assesses the potential role of adaptation methods in reducing farmers' vulnerability to climate change in Tanzania.

Chapter Four looks at the various adaptation methods that Tanzanian farmers choose to implement to reduce the negative impacts of climate change on agricultural yields and examines the factors influencing the farmers' choice of adaptation methods.

Chapter Five analyses the factors affecting household participation in the United Nations' Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation (REDD+) in Tanzania.

Finally, Chapter Six presents the conclusion and policy recommendations of the study.

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Chapter 2: Climate Change Vulnerability, Adaptation and Mitigation: A Review of the Literature

Abstract

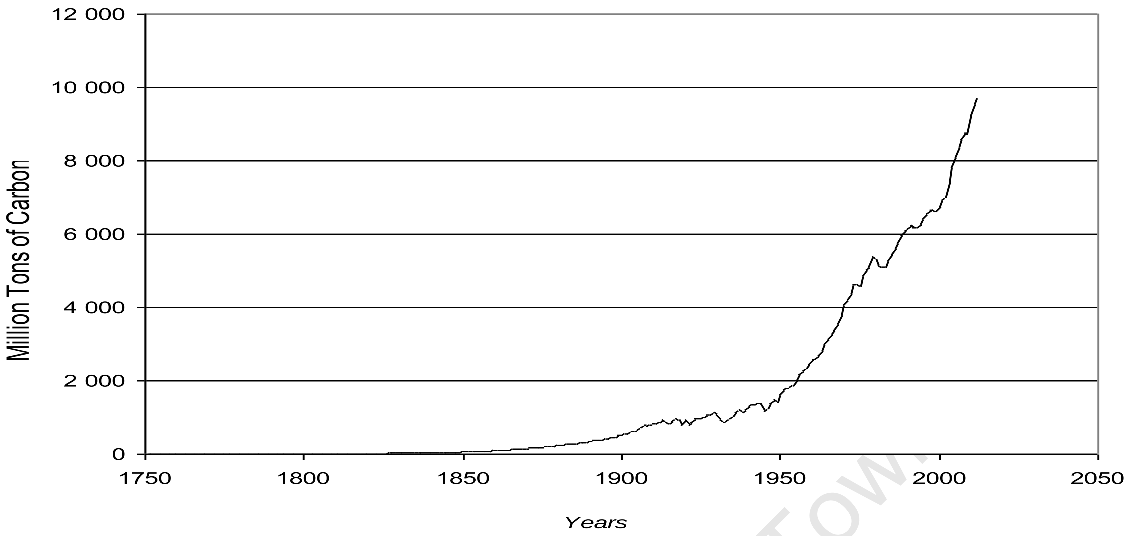
Climate change appears to be an inevitable challenge with which communities have to deal both currently and probably for many more years to come. This review is an effort to provide an overview of findings from the literature on climate change vulnerability, adaptation and mitigation. The literature review is divided into (a) the introduction section which reviews the evidence of Greenhouse gas emissions by gas and source, and projected non-CO_2 emissions; (b) findings on farmers' perceptions of climate change; and (c) evidence for farmers' vulnerability, and their adaptation to and mitigation of climate change. The literature reveals that farmers in many places are aware of climate change and are making some effort to reduce its negative impact through adaptation and mitigation.

Key words: *Climate Change, farmers, Vulnerability, Adaptation, Mitigation, Greenhouse gas, Non-CO_2 emissions.*

2.1 Introduction

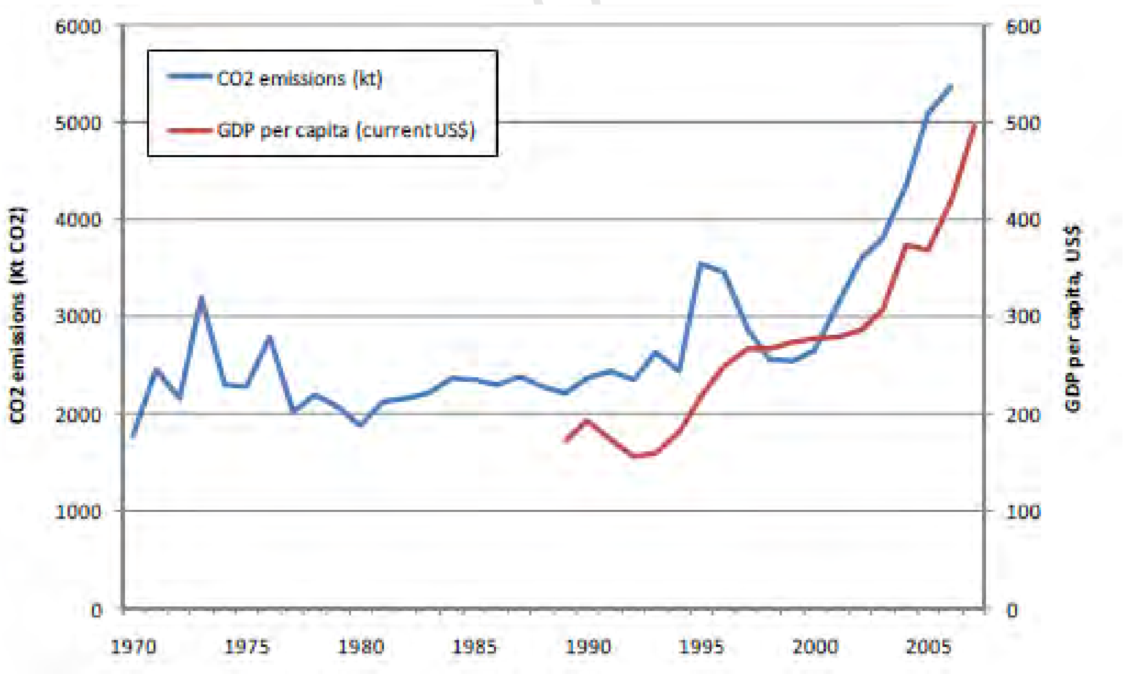
This chapter aims at reviewing theoretical and empirical evidence regarding vulnerability to climate change as well as possible adaptation and mitigation. The chapter includes a discussion of relevant literature from countries; such as Ethiopia, Kenya, South Africa, Zambia, Zimbabwe; that have some significance for improving an understanding of the Tanzanian case. The introduction of this chapter provides a general review of the evidence of Greenhouse gas emissions by gas and source, and projected non-CO_2 emissions. This is followed by a review of literature on farmers' perceptions, vulnerability, adaptation to and mitigation of climate change.

The atmospheric scientists believe that the environment is affected and will continue to be affected by climate change. This is because of the increasing trend of carbon dioxide emissions as shown in EPI (2013), presented in figure 2.1. Earth Policy Institute compiled data from Boden et al (2010), Carbon Dioxide Information Analysis Center (2012), and U.S. Geological Survey (2011). The same increasing trend of carbon dioxide emission has been observed in Tanzania as shown in figure 2.2 and the projections for GHG emissions shown in figure 2.3 reveals the continuation of the increasing trend (GCAP, 2010). Human activities that release large amounts of carbon increase the amount of carbon dioxide concentration in the atmosphere. Carbon dioxide in the atmosphere causes a greenhouse effect which affects the temperature of the earth. When the amount of heat in the atmosphere increases, it results in a change in climate. This change in their environment affects the life and livelihoods of many people. Although the effects of climate change are expected not to be the same in all countries, some countries, especially developing ones, are expected to be more vulnerable because of their inability to deal with these negative impacts. Besides their impact on the income levels of countries, it is also noted that hotter countries are expected to experience more severe impacts because of increasing risks of generating abrupt and large scale changes in climatic variables (Stern, 2007). In this case, it is obvious that a small increase in temperature will be felt more by the countries that already experience high temperatures than those with low temperatures. The impacts of changing climate on people's lives are anticipated to be significant especially if efforts are not made to reduce them. It is expected that the consequences of climate change are determined by socio-economic and other factors. For example, migratory patterns will play a role because people increase their exposure to environmental stress when there is massive population movement. This is because they will reduce per capita resources available in the areas in which they settle and that is going to have a direct impact on the environment.



Source: EPI from BP; CDIAC; USGS (2013) [13]

Figure 2.1: Global Carbon Dioxide (CO_2) Emissions from fossil-fuels (1751-2012)



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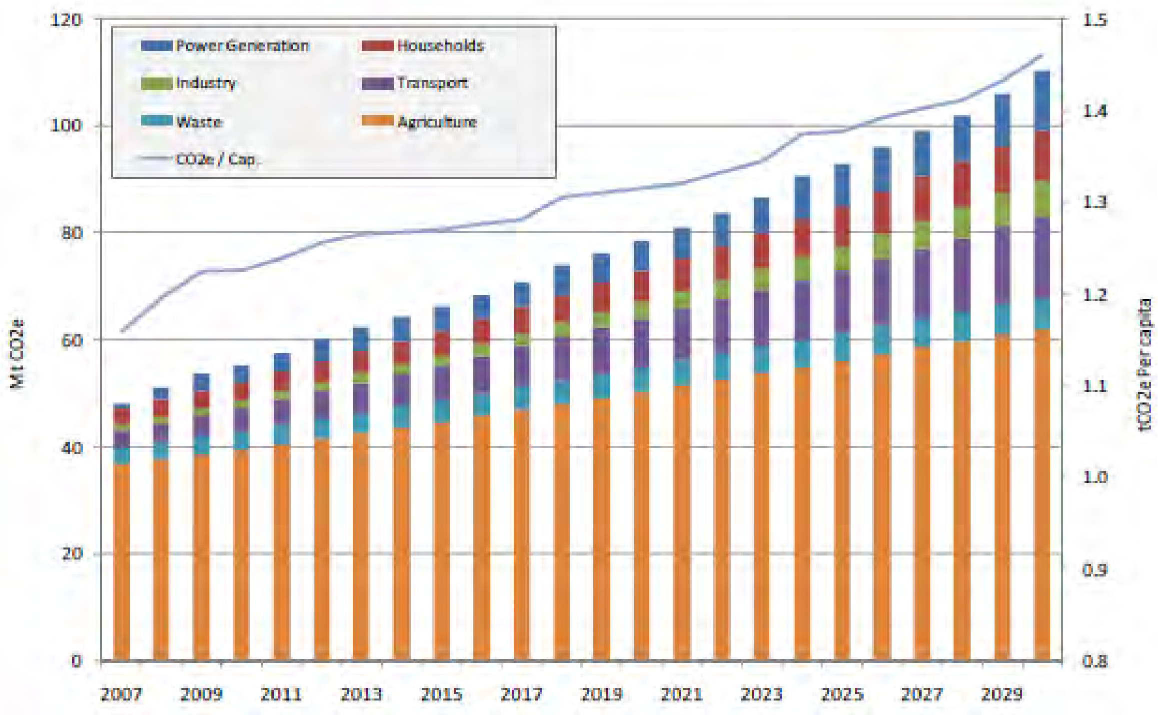
[13] Earth Policy Institute. 2013. compiled data using 1751 to 2009 from T. A. Boden, G. Marland, and R. J. Andres, "Global, Regional, and National CO_2 Emissions," *Trends: A Compendium of Data on Global Change* (Oak Ridge, TN: Carbon Dioxide Information Analysis Center, 2012); 2010-2012 emissions calculated by Earth Policy Institute from energy consumption in BP, *Statistical Review of World Energy June 2013* (London: 2013), and cement production in U.S. Geological Survey (USGS), *Mineral Commodity Summaries 2011* (Reston, VA: 2011):39; USGS, *Mineral Commodity Summaries 2012* (Reston, VA: 2012):39; USGS, *Mineral Commodity Summaries 2013* (Reston, VA: 2013):39.

Source: GCAP (2010)

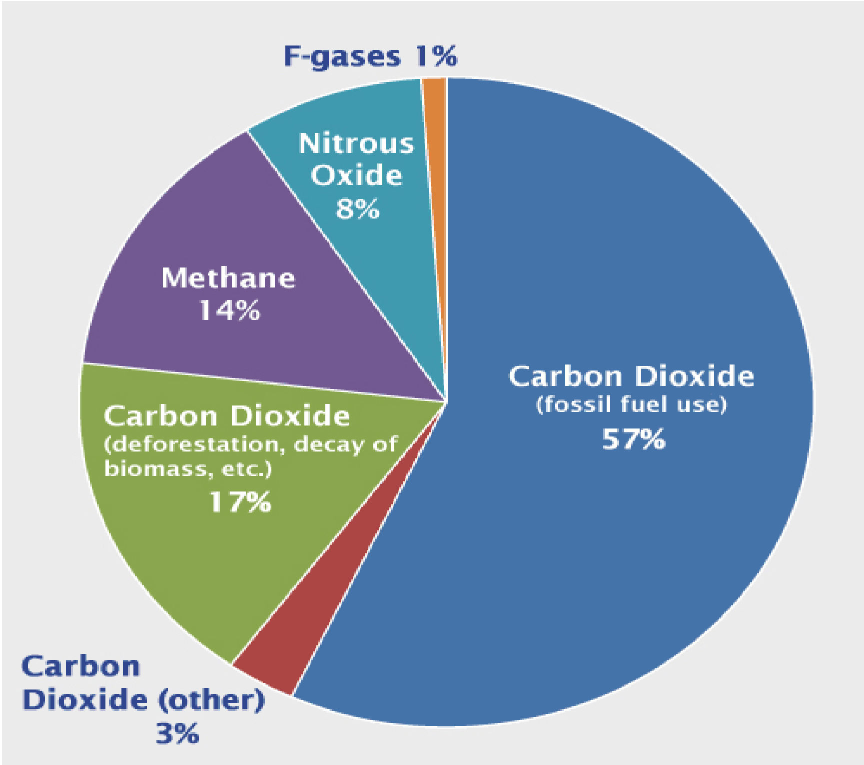
Figure 2.2: Historic trend of CO2 emissions and GDP per capita levels in Tanzania



Source: GCAP (2010)

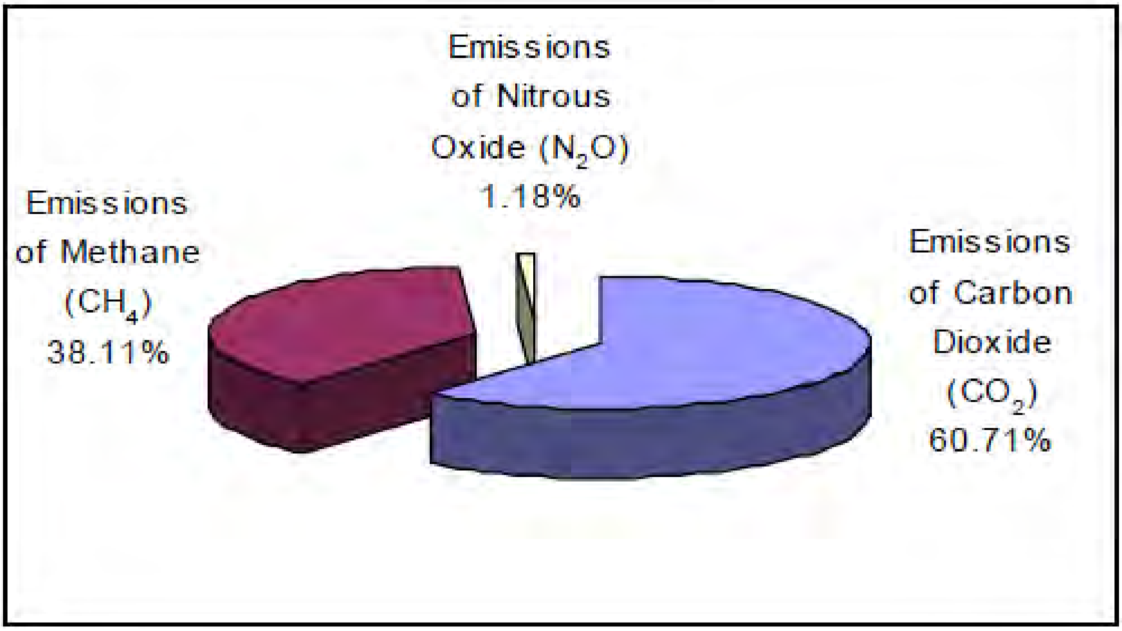
Figure 2.3: CO2 emissions projections for Tanzania (2007 – 2030)

Globally it is reported that human activities are the main contributor to greenhouse gas emissions. Figure 2.4 presents the percentage of greenhouse gases emitted as reported by IPCC (2007). The gases include carbon dioxide (this is carbon dioxide coming from fossil fuel emissions and also from deforestation and the manner in which people use land). Methane (this is mainly caused by agricultural activities, the way people handle waste and energy use); nitrous oxide (caused by agricultural activities, especially the use of fertilizers); and fluorinated gases (caused mainly by industrial activities). Carbon dioxide is reported to be the main greenhouse gas emitted globally which contributes to 74 percent of the total greenhouse gas emitted. The same applies to Tanzania. Tanzania emits 60.7 percent of the total greenhouse gas as shown in figure 2.5 (URT, 2003).



Source: Intergovernmental Panel on Climate Change (2007)

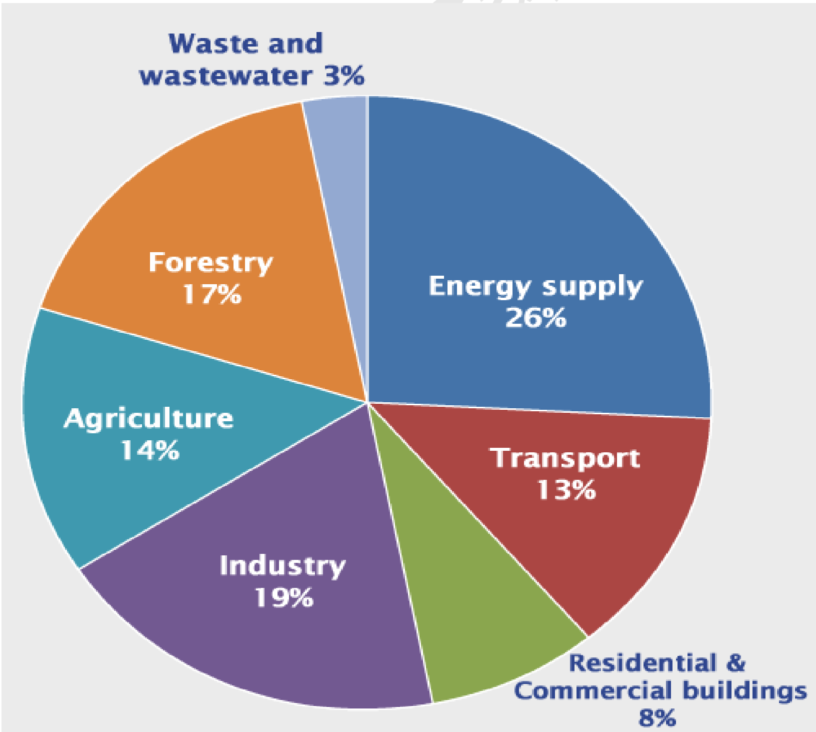
Figure 2.4: Global Greenhouse Gas Emissions by Gas



Source: United Republic of Tanzania (2003)

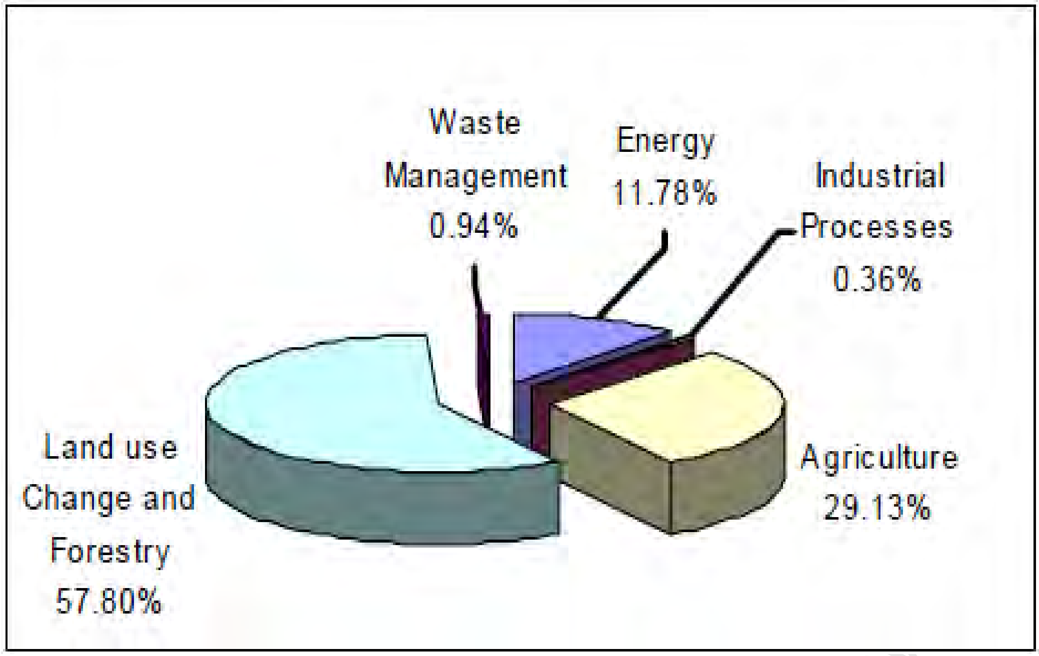
Figure 2.5: Tanzania Greenhouse Gas Emissions by Gas with 100 year Time Horizon for 1990

The Intergovernmental Panel on Climate Change (2007) in their fourth assessment report also mentioned several economic activities that lead to greenhouse gas emissions, as shown in figure 2.6. The main source is reported to be energy supply (this is mainly caused by burning of fossil fuels in the process of energy production). Other sources are industry (caused by burning fossil fuels in the industrial sector, including emissions from chemical, metallurgical, and mineral transformation); Land Use, Land Use Change, and Forestry (LULUCF) (this is triggered by deforestation, land clearing for agriculture, and bush fires); agriculture (caused by the way people handle land for agriculture, livestock, and biomass burning); transportation (caused by burning fossil fuels in the transport sector); commercial and residential buildings (caused by burning fuels for building heating and cooking in houses); and waste and wastewater (caused by waste products made of fossil fuels, such as plastic bags and synthetic textiles, and wastewaters). While energy supply is reported to be the main source of global greenhouse gas emission, figure 2.7 shows that land use change and forestry are the main source of greenhouse gas emission in Tanzania (URT, 2003).



Source: Intergovernmental Panel on Climate Change (2007)

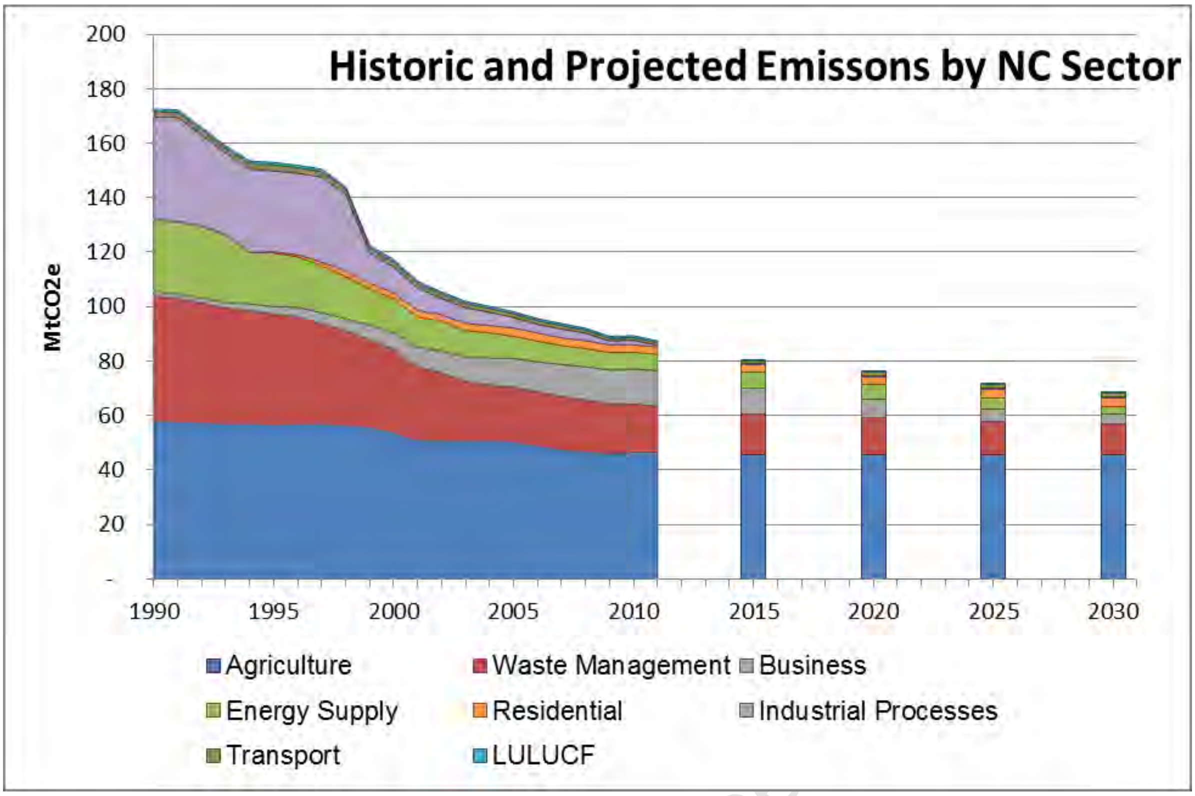
Figure 2.6: Global Greenhouse Gas Emissions by Source



Source: United Republic of Tanzania (2003)

Figure 2.7: Tanzania Greenhouse Gas Emission by Source

Greenhouse gas emissions can be reduced in different ways. One method is by reducing the demand for the goods that are made via processes that release carbon dioxide. There are also non carbon dioxide (non-CO_2) gases that play a significant role in global warming. In this case, another way of reducing greenhouse emissions is by reducing non-fossil gas emissions that come from land use and agricultural activities. As it is for CO_2 gases, the reduction of emissions from non-CO_2 gases is very important and should be considered in mitigation strategies. Projections from the Department of Energy and Climate Change (2013) of the UK Government highlight that there where non-CO_2 emission reductions from different sectors of the economy globally from 1990 to 2011. Figure 2.8 shows that from 2011 to 2030, a significant amount of carbon dioxide emission reduction will come from changes in the agricultural sector. This can be explained by the declining dependency of many countries on the agricultural sector. Figure 2.8 illustrates the finding that if appropriate measures are taken in different sectors of the economy, there is a possibility of reducing non-CO_2 greenhouse gas emissions.



Source: Department of Energy and Climate Change (2013)

Figure 2.8: Summary of projected non-CO_2 GHG emissions by National Communication Sector ($MtCO_2e$)

Stern (2007) explains that by the 2050s the predicted effects of climate change in terms of temperature will be 2°C to 3°C. This significant change threatens the livelihood of poor communities in developing countries. People in tropical countries especially are threatened by changes in climate not only because of their substantial dependence on agriculture, but also because in these countries population growth is fast whereas economic growth is comparatively slow. Developing countries that experience rapid economic growth are expected to be in a position to deal with the negative impacts of climate change. However, those countries that continue to struggle with their economic growth are expected to show an increased vulnerability. In addition to the slow economic growth that appears as a constraint to adapt to or be able to mitigate climate change, the vulnerability of developing countries is also due to exposure[14] to fragile environments experienced by those countries. The challenge that the world is facing is to reduce the negative impacts of climate change by means of adaptation and mitigation.

[14] Many developing countries are in tropical areas where they already experience climate extremes. A slight change in climate affects them more than the countries that are not in these areas.

In trying to reduce greenhouse gas emissions, there are some costs incurred. Households are likely to be responsible for paying for the costs of reducing emissions through their involvement in either adaptation or mitigation or both. There are many ways that households can pay for reducing emissions including forgoing agricultural outputs in order to reduce emissions from deforestation and forest degradation. The cost of reducing deforestation and forest degradation seems to be less expensive for households in developing countries in mitigating climate change. It is less expensive because there is no involvement of new technologies or techniques in reducing or stopping deforestation. On top of that, developed countries are stepping in to pay for developing countries' involvement in ending deforestation as compensation.

2.2 Farmers' perceptions of climate change

In studying the impact of climate change on agricultural activities, it is important to investigate if the farmers who are the main players in agriculture are aware of changing climate. Whether farmers' perceptions about climate change are warranted can only be confirmed by the observed statistical data collected by meteorological stations. Many studies reveal that farmers are very much aware of these changes even though evidence in some places is negligible (see for example Deressa et al, 2011; Gbetibouo, 2009; Ishaya & Abaje, 2008; Juana et al, 2013; Mertz et al, 2009; Nzeabide et al, 2011; Tambo & Abdoulaye, 2013; Yaro, 2013).

Generally, farmers use rainfall (or precipitation) and temperature incidence to refer to deviations from the usual climate. The differences can be in terms of the amount or the timing. Farmers tell stories of the current patterns of rainfall and temperature compared to the past years. For example, there are some places where farmers say that the timing of rainfall seasons is not as it used to be. This means, rainfall now comes too early or too late (Nhemachena & Hassan, 2007; Baudoin et al, 2013). It is not surprising to find that perceptions of climatic variables relate to the economic activities in which the household engages. The literature mentions strategies such as the use of irrigation, different crop varieties, the planting of trees, shortening of growing seasons, maximizing of water use practices, and extension of farming land to be the most commonly used adaptation methods in many countries (Deressa et al, 2009; Ishaya & Abaje, 2008).

Farmers' perceptions are important because these influence their decisions on adapting to and mitigating climate change. The probability that the farmer will adapt increases when the risks associated with climate change are perceived to be high (Grothmann & Patt, 2005). The farmers' perceptions are obviously influenced by their experience. Many studies reveal that farmers who have been farming for a long time are more aware of long term changes in climate variables than others (Bryan et al, 2013; Wiid & Ziervogel, 2012; Hisali et al 2011). Following the history of the patterns of rainfall and temperature, farmers are in a position to tell stories about changes. Yaro (2013) added that the difference between climate change perceptions between smallholders and commercial farmers is that commercial farmers understand better the science of climate change while smallholder farmers just have localised explanations.

Whether farmers' perceptions about climate change are warranted can only be confirmed by the observed statistical data collected by meteorological stations. Gbetibouo (2009) assessed the accuracy of farmers' perceptions by comparing them with the actual temperature and precipitation recorded in the area over 20 years. The study revealed that farmers' perceptions matched the trends of temperature and precipitation recorded. The same kind of comparison by Vedwan & Rhoades (2001) found that farmers in Zambia perceive changes in climate as a temporary displacement of the weather cycle. This study showed that the majority of smallholder farmers in Zambia believed that the changes are caused by supernatural forces (Nyanga et al, 2011). In that study, farmers expressed the view that climate change is a punishment for peoples' misbehaviour towards God and the ancestral spirits. There are some studies that segregate farmers' perceptions about changes in each climate variable. While many farmers are aware of the changes in rainfall and temperature, in Mertz et al (2009) it is revealed that famers in the rural areas of the Sahel perceive wind and rainfall to be the most changing climate variables in that region.

2.3 Farmers' vulnerability and adaptation to climate change

Despite the economic and social importance of the agricultural sector to the majority of people living in rural areas, the sector has been facing many challenges, climate change being one of the more severe. This is because the growth of the sector is heavily reliant on climatic variables. Farmers are expected to respond to these changes in climate by implementing activities that enable them to deal with the negative impact of these changes. It is believed that when farmers are able to adapt to climate change they not only reduce the negative impacts but also reduce the likelihood of being vulnerable.

Many farmers, especially smallholder farmers, find themselves vulnerable to climate change. Farmers are considered to be vulnerable when they are exposed to climate risks and their ability to cope with the situation is minimal. Researchers measure vulnerability in order to find out the relative loss farmers experience in the presence of climate change. The findings are used as a basis for advising farmers on adaptation methods appropriate to their situations. The literature reveals that there are many factors that render smallholder farmers vulnerable (see for example Molua, 2002; Gbetibouo & Ringler, 2009; Deressa et al, 2009; Thorlakson, 2011; Baudoin et al, 2013; and Juana et al, 2013). One of these is failure to adapt due to economic constraints. In some places where the costs of implementing different adaptation methods are high, smallholder farmers fail to cope and as a result future poverty looms. In Wilk et al. (2013), lack of funding for implementing improved inputs, restricted awareness, current agricultural practices, and an absence of a tradition of long-term planning are outlined as the main reasons why smallholder farmers in the Upper Thukela basin in South Africa are vulnerable.

Being aware of climate change, farmers in many places are cushioning themselves against the situation. Adaptation is one of the major ways of reducing vulnerability. The capacity for adapting nevertheless alters with changes in farmers' household economic conditions and other important factors (Smit & Wandel, 2006). For instance, population growth in the household, other things remaining constant, is expected to reduce the capacity of the household to adjust.

Adaptation to climate change is not a new phenomenon to smallholder farmers in Africa. Although many smallholder farmers do not have access to information through agricultural extension officers, they may still obtain information from relatives, friends and neighbours (see Adesoji & Ayinde, 2013). Farmers have long been known to adapt through a variety of methods.[15] Some of the adaptation techniques are influenced by cultural practices, as Head (2010) shows. Tracing past climate history within farming communities should lead to agreement that there is alteration in climates and encourage farmers to change traditional methods of agriculture to adjust to this change. Below et al. (2010), in reviewing the micro-level practices of small-scale farmers in Africa, revealed that there is a wide range of practices used by small-scale farmers to deal with the negative impacts of climate change.

[15] Farmers have been observed to be flexible in their farming activities. This situation has existed for a long time. Most farmers are very sensible in following climatic conditions and adjusting to ensure their productivity.

There are some good reasons why farmers would decide how to adapt to these changes. When farmers' decisions to adapt to climate change in Benin are modelled, Yegbemey, et al. (2013) reveal that socio-economic and demographic characteristics of the farmers' households together with property rights have a strong influence on farmers' decisions to adapt. Di Falco et al (2011) examine the factors that influence farm households' adaptation in Ethiopia and found that farmers who are well informed about climate change, those who have access to credit and to formal and farmer-to-farmer agricultural extension information, are likely to adapt more effectively. Information plays a significant role in farmers' decisions; this information can be about climate change or adaptation methods. Some farmers may not be aware of climate change or they might be aware of the changing climate but do not know what they should do to deal with it.

There are a few farmers who manage to make large investments in dealing with the negative impacts of climate change. Bryan et al (2013) report that examples of some of these large investments are the introduction of irrigation and tree planting (agroforestry). Investing in irrigation requires sufficient capital especially if water sources are not close to agricultural plots. Other farmers decide to reduce household consumption and/or use the savings accumulated in previous years as adaptation strategies (Hisali et al 2011). This does not appear to be sustainable because reducing current household consumption and using savings meant for the future may actually increase the probability of farm households being more at risk.

In conditions of climate change, farmers find themselves needing to decide on their adaptation strategies. The choice of adaptation strategies used by farmers is influenced by several factors. Agroforestry is mentioned as one of the best techniques that farmers especially those in arid regions, can use to reduce their vulnerability (see Thorlakson, 2011; World Bank, 2008; Challinor et al, 2007; and Verchot et al, 2007)[16]. Deressa et al (2009) reveal that the choice of adaptation methods among farmers in the Nile basin of Ethiopia is influenced by the income levels of the household heads, access to extension and credit, and agro-ecological settings, among other factors. The choice of adaptation strategies also depends on the scale of farming in which the households engages. It is not easy for commercial farmers to use non-agricultural adaptation strategies to cushion themselves as they depend on agriculture to generate income. This was revealed by Baudoin et al (2013) when comparing the adaptation strategies that are

[16] Climate change is expected to further decrease rainfall in arid regions. In this case, planting trees in the cropping system is helpful in increasing agricultural production.

mostly used by independent farmers and project farmers. Their results reveal that independent farmers mainly choose non-agricultural strategies (for example doing other jobs) while project farmers rely on agricultural adaptation strategies (for example, improved seed varieties).

Despite farmers' awareness of, and vulnerability to, climate change, there are still many farmers who are not adapting due to several constraints. Some of these are lack of knowledge regarding suitable adaptation methods, lack of credit, and limited access to water for irrigation (Gbetibouo, 2009). Many smallholder farmers have subsistence incomes that do not allow them to invest in large projects like irrigation systems especially if the farming plots are far away from water bodies. Lack of efficiency and corruption of local state representatives are also mentioned as some of the reasons that smallholder farmers in Benin lack capacity to improve their agricultural strategies (Baudoin, et al. 2013). This is also relevant for other African countries. The agricultural officers are reluctant to attend to smallholder farmers needs especially if they do not have money to offer them. This results in farmers relying on their farming experiences to deal with obstacles when they arise in ways they see fit but which might not be the best approach.

Unlike the climate change situation in higher-latitude developed countries, a small increase in temperature leads to a decline in crop products in tropical countries where the crops are grown in temperatures close to critical thresholds, (Stern, 2007). The changing climate has impacted negatively on the majority of smallholder farmers in Tanzania, which is a tropical country, by reducing their agricultural productivity and thus endangering their welfare. In this case, there is a need for the government of Tanzania to help smallholder farmers reduce the negative impact of climate alteration on their livelihoods. This could reduce rural poverty and assist the country's economic development. It may be initiated by conducting different types of research that will lead the way in providing data to help farmers to deal effectively with climate change. One way of doing this is by understanding the prospects and challenges that farmers come across in trying to implement adaptation that will help them reduce their vulnerability.

Adaptation is not the sole strategy for dealing with the negative impact of climate change. The evidence from the literature shows that countries can also mitigate climate change. Besides analysing farmers' vulnerability and examining the factors affecting their adaptation, research is required around the question of the manner in which households should be involved in the United Nations Collaborative Program on mitigation towards climate change. One of the most influential programmes suggested by the United Nations is REDD+, which focuses on reducing emissions from deforestation and forest degradation, the role of forest conservation, sustainable forest management and enhancement of forest carbon stocks especially in developing countries. This programme is introduced as a technique for encouraging countries to conserve forests through financial incentives regulated at the international level. In this study, we also investigate whether households in Tanzania are willing to participate in the programme if they are offered economic incentives. For those household that are willing to participate, the study investigates the minimum amount that they are willing to accept for this participation.

2.4 Deforestation, forest degradation and the role of REDD+ in mitigation

In 1998, Tanzania reported in its Forestry Policy that it had about 33.5 million hectares of forest cover (URT, 1998). The forest cover consists of forests and woodlands. Forests play a major role in the carbon cycle. According to Lopes (2011), more than 50 percent of terrestrial carbon is stored in forests and when the forests are cut or burned the carbon dioxide is released into the atmosphere. The argument here is that forests tend to absorb the carbon dioxide in the air, which is stored in the trees and soils when the trees grow. When the forests are cut or burned the carbon dioxide that has been stored is released back into the atmosphere through oxidation or a decaying process (Lopes, 2011). In Tanzania, where deforestation is believed to be very high, it is important to understand the economics of carbon preservation. It has been pointed out that the rate of deforestation in Tanzania will continue to be high for the next few years if proper actions to stop it are not taken. In 2000, Tanzania was fourth out of twelve countries that had the highest deforestation rates (Brent et al. 2010). In this case, therefore, this deforestation rate contributes greatly to carbon dioxide emissions as well as eroding the extensive net carbon sink.

Worldwide, agriculture is said to be the major driver of deforestation and forest degradation followed by logging which is increasing due to increased urbanisation and mining (Geist and Lambin, 2002; Morton et al., 2006; and Rudel, 2007). In Africa, the main driver of deforestation is small-scale agriculture and production of charcoal for domestic and commercial uses (Fisher 2010). Herold et al. (2011) reveal that the drivers of forest degradation are the harvesting of timber products, fuelwood (this consists of firewood and charcoal), and fodder. In Tanzania, agriculture is also mentioned as the main driver of deforestation and forest degradation. This is not surprising as it is the major economic activity carried out by more that 50 percent of the population. It should also be noted here that Tanzania is currently supporting its Agriculture First Policy (also called Kilimo Kwanza in Kiswahili). This policy promotes agricultural transformation through an emphasis on productivity and tradability. This includes transforming peasants and small and medium scale farmers into commercial farmers. This can partially be achieved through expansion of farmers' agricultural land, which involves clearing new land for agriculture. In estimating the cost of REDD+ pilot projects in Tanzania, Merger et al. (2012) emphasise agriculture (shifting cultivation) as the main driver of deforestation in Kigoma, Kilosa and Lindi districts in Tanzania. It is important to identify and understand the main drivers of deforestation and forest degradation in order to strategise how to reduce emissions from these practices. Table 2.1 classifies the forest types (ecosystem) in Tanzania. There are seven forest types in Tanzania as classified by UN-REDD (2009). The classification is based on the location of forests, major drivers of deforestation and forest degradation, and other characteristics. The forest types identified are Miombo woodland, Coastal forest, Eastern Arc and other montane catchment forests, Mangrove forests, Non-marine Wetlands, Acacia Savannah woodland; and Guinea-Congolean forest. This study covered five out of the seven forest types. It excludes Mangrove forests and Guinea- Congolean Lowland Forests.

Table 2.1: Forest Ecosystems in Tanzania: Location, Threats and Characteristics

Ecosystem/ forest type	Extent/location	Main deforestation and forest degradation drivers and threats	Other consideration
Miombo Woodlands	≈ 220,000 sq km, about 2/3rds total forest, esp. west & south: Tabora, Morogoro, Iringa, Manyara, Tanga regions	Medium level pressure from agriculture (e.g., tobacco in Tabora area) and charcoal	Mostly outside forest reserves or other protected areas; valuable timber spp.
Coastal Forests (excluding mangrove)	≈ 8,000 sq km in 50-200 km coastal belt - Dar es Salaam, Tanga, Lindi, Pwani & Mtwaraareas	High pressure from illegal logging, charcoal, biofuel plantations and agriculture.	High levels of biodiversity and endemism (except thicket forest); tends to be small isolated patches, especially hilltops, islands
Eastern Arc and Other Montane Catchment Forests	Eastern Arc ≈ 3,500 sq km; mainly found in national forest reserves (NFRs) and Nature Reserves at top of mountain blocks in Iringa, Morogoro, Tanga & Kilamanjaro regions	High pressure from fire, encroachment, illegal logging for valuable timber spp., slash & burn farming	Very high levels of endemism and biodiversity; high tourism potential
Mangrove Forests	≈ 1,150 sq km located in NFRs along coastal strip.	High pressure for poles, timber, boat building (especially near towns), shrimps & salt pans	High carbon levels and critical role for climate change adaptation

Ecosystem/ forest type	Extent/location	Main deforestation and forest degradation drivers and threats	Other consideration
Wetlands (non-marine)	≈ 2,000 sq km, mainly found mainly in Morogoro, Iringa and Tabora regions	High pressure from irrigated rice, livestock grazing	Important water catchment functions; high carbon levels
Acacia Savannah Woodlands	≈ 175,000 sq km in north & central Tanzania, mainly in protected areas (including game reserves)	Medium-low pressure from woodfuel, poles, subsistence farming, grazing	Game parks – tourism; livestock a key component of ecosystem
Guinea-Congolean Lowland Forests	≈ 6,700 sq km in Kagera & Mwanza regions in NW Tanzania (Lake Victoria Basin); mainly National Forest Reserves	Medium-high pressures from agriculture, esp. livestock, charcoal, near urban areas	High biodiversity values; includes Podocarpus swamp forests

Note: Adopted from UN-REDD (2009)

It is reported by a number of studies that globally the carbon stored in forests is about 289 gigatonnes (see, for example FRA, 2010). Currently, deforestation contributes about 12 percent of total global carbon dioxide emissions (Van der Werf et al, 2009). This is the second highest carbon dioxide emitter after emissions from burning fossil fuels. Thus, its contribution to greenhouse gas emissions is significant and should not be ignored. Accordingly, appropriate actions need to be taken to prevent deforestation.

In order to reduce carbon emission from deforestation and forest degradation, the United Nations Framework Convention on Climate Change (UNFCCC) developed a framework known as Reducing Emission from Deforestation and Forest Degradation (REDD+). This framework is based on the belief that when the forest cover is removed, there will be massive emissions of greenhouse gases which will then result in climate change. It has been pointed out by many scholars that recently the carbon dioxide emissions from deforestation and forest degradation are greater than those that emanate from the transport sector (Stern, 2007; Fry, 2008). Thus, reducing deforestation and forest degradation would make a major contribution to decreasing carbon dioxide emissions in the atmosphere. REDD+ offers developing countries an incentive to avoid or reduce deforestation and forest degradation by providing them with economic incentives. It is highly likely that Tanzania will gain by engaging with the REDD+ programme.

REDD+ is thus one of the important mechanisms in mitigating climate change. In this framework, developed countries transfer funds to developing countries in return for buying carbon credits from them. The governments in developing countries can gain from this project by formulating and implementing policies that protect forests. The benefits do not only accrue to governments. The local forest communities may also benefit from REDD+ funds by forgoing the direct and indirect benefits they get from forests and participating in the programme. It is well known that to local forest communities, forests are more valuable when they are cut down than when they are left standing (Parker et al, 2008). In order to incentivise them to participate in the programme, positive financial incentives are needed. Since most of the forest communities are likely to be more vulnerable to climate change because of their high dependence on rain-fed agriculture, their participation in the programme will give them two main benefits: One is the financial benefits from the programme and the other is the indirect benefit of maintaining the eco-system. This leads us to concur with the three justifications (3E+ criteria) underlying REDD+, as mentioned in Angelsen et al. (2009) namely (i) This programme is an effective method of reducing greenhouse gases; (ii) It is cost-efficient because there is no need to apply or invent expensive technologies to achieve the desired goals; (iii) It is equitable since developing countries are also included in the efforts to mitigate global climate change. Di Gregorio et al. (2013), nonetheless, question the equity argument and REDD+. They argue that equity as a concept is not understood in the same way by the different actors. It has been observed in four REDD pilot countries (Brazil, Indonesia, Peru and Vietnam) that policy makers focus on international rather than national equity concerns while neglecting the recognition of local forest communities rights in decision making (Di Gregorio et al., 2013).

In Tanzania there is a framework that is guiding the nation towards the improvement of the REDD+ strategy that was initiated in 2008 by the National REDD+ Task Force. The National REDD+ Task Force is operating under the Vice President's Office in the Department of the Environment. National REDD+ strategies have been pointed out in Otsyina et al. (2008), as proposed by different stakeholders. Some of the strategies proposed are (i) the development of a carbon trading concept note, (ii) consultations among stakeholders to identify roles and responsibilities and come to agreement on the essential principles of REDD; (iii) development of a forest carbon partnership facility (FCPF) and a readiness plan idea note (R-PIN); (iv) identification of deforestation spots for pilot studies; and (v) highlighting areas of implementation that are found to provide a good entry point for REDD. The National REDD+ strategy provides guidelines on how to convince the appropriate stakeholders to get involved in the programme, on the importance and benefits of the programme to the stakeholders, and in what way the programme benefits are going to be shared by potential stakeholders. REDD+ pilot programmes were chosen from the previously existing community-based forest management (CBFM) projects which are a form of participatory forest management (PFM) programmes (Robinson et al., 2013). The study suggests that the use of community-based forest management in implementing REDD+ can achieve REDD+ objectives only if the key forest change drivers are the ones who receive REDD+ funds.

According to Otsyina et al. (2008), among the important issues pointed out as relevant for the effective implementation of REDD, are the identification of strategies and modalities for promoting awareness and development as well as disseminating REDD information; managing and sharing a database of information concerning REDD; conducting training and human resources capacity building in all phases of the project (development, management, and certification); as well as certification mechanisms and procedures. Looking at these issues, it appears that REDD strategy is suitable for the forestry sector as well as the REDD+ program. In this case therefore, if Tanzania manages to convince stakeholders that their livelihood depend greatly on forests, the country will benefit from the positive economic incentives that REDD+ provides and at the same time it will contribute towards the United Nations program on mitigating climate change. As has been happening in many projects that involve different components, there is a concern around how REDD+ benefits will be distributed among stakeholders especially forest communities. There are many studies criticising the expected co-benefits of the REDD and REDD+ projects. Brown et al. (2008) query how REDD and REDD+ benefits will be shared. The emerging carbon market especially the "Green New Deal" is also questioned (Boykoff, 2009; Lohman, 2009; Bumpus & Liverman, 2008). This study aims to design strategies for benefit sharing that will improve local livelihoods in such a way that will motivate the households in forest communities to participate in the REDD+ program.

2.5 Conclusion and the way forward

This chapter reviewed some of the literatures on climate change vulnerability, adaptation and mitigation and explored farmers' perception of climate change. There is no doubt that climates are changing. Many studies confirm this (see for example Stern, 2007; Hinzman, et al, 2005; Kaser et al, 2004; Walther et al, 2002; and Thompson, 2000;). Several studies also confirm that farmers are aware of changes in different climatic variables and they are attempting to reduce their vulnerability through adapting to and mitigating climate change.

Tanzania is one of the countries whose economies depend on agriculture. Farmers in Tanzania therefore need to cushion themselves against the negative impacts of climate change. Like farmers in other countries, Tanzanian farmers can reduce their vulnerability through adaptation and mitigation. Failure to adapt has a negative impact on different economic sectors, including agriculture. Farmers can only engage in fighting against climate change according to their perceptions of this phenomenon. It is therefore important to study the perceptions of Tanzanian farmers and investigate how they are protecting themselves from its negative impacts. This is an important motivation for this study and has been addressed in the subsequent chapters which cover the perceptions and knowledge of climate change among farmers from different agro-ecological zones in Tanzania.

The literature reviewed presents different work by others on vulnerability, adaptation and mitigation. However there are some gaps that can still be filled by this study. Farmers' households are not homogeneous; they have different socio-economic characteristics. This study, therefore, identifies the characteristics of the farmers' households that make them vulnerable. Apart from farmers' socio-economic status, farmers reside in different agro-ecological zones which have different climatic condition. It is therefore important to analyse farmers' vulnerability according to their area of residence (where their agricultural plots are). This study also proposes that it is important to find out whether the adaptation methods that farmers use reduce their vulnerability. This will help in recommending to the Tanzanian government effective policies that should be formulated and implemented to assist farmers to cope. The study also recognises that the role of mitigation is important in reducing the negative impacts of climate change. In this case, therefore, it is essential to find out whether Tanzanian households are willing to participate in the United Nations mitigation programmes through REDD+. This study is also using the methodologies that are different from the one used to address the same problems in other places. The methodological frameworks are presented in the respective chapters of the study.

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Chapter 3: The role of effective adaptation methods in reducing farmers' vulnerability to climate change in Tanzania

Abstract

This study examined the characteristics of those farmers' households which are most likely to experience poverty in the future as a result of climate change, using 556 randomly selected households in Tanzania. The study found that farmers' households that were vulnerable include: those that reside in the plateau agro-ecological zone, those that use crops that are resistant to drought as their dominant adaptation method, large households, male headed households, and households with heads that have more than primary school education. Using a binary logit model, the study found that there are some adaptation methods that are vital in reducing current and future household poverty. Farmers who use irrigation as their dominant adaptation method have a 1 percent lower probability of falling below the poverty line while farmers who use short season crops have a 12.1 percent lower likelihood of being vulnerable. Thus, the results of this study confirm that the choice of adaptation method matters in reducing the negative impact of climate change. Thus the major role that the Tanzanian government needs to occupy itself with regarding the effects of climate change on smallholder agriculture is to help farmers overcome the constraints they face in adopting appropriate adaptation methods to counter climate change. The results from the binary logit model further show that the age of the household head, household size, farm size, access to credit, growing maize and sorghum as major crops, and the fact that the household has non-farm income are important factors in reducing farmers' current and future poverty related to climate change.

Key words: *Vulnerability, adaptation methods, agro-ecological zones, smallholder farmers, climate change,*

3.1 Introduction

Climate change exposes farmers to conditions with which they are not familiar. According to Nelson et al. (2009), agricultural productivity is expected to decrease by 10 to 20 percent over the next forty years due to changes in climate. In Tanzania, farming is strongly dependent on climate variables (mainly rainfall and temperature), which make these factors important determinants of agricultural productivity. In Tanzania, a country where more than 80 percent of the population engages in rain-fed agriculture, the variability of climate leads to a decrease in agricultural outputs and hence negatively impacts the welfare of the farmers.

Some farmers are making efforts to deal with the potential loss of output through the use of different adaptation methods to climate change. The choice of adaptation methods depends on many different factors. Research suggests that socio economic and environmental factors may be important determinants of farmers' choice of adaptation methods. (Deressa et al, 2009). Institutional factors and economic structure can also be important determinants. Farmers' willingness to adapt to climate change will have an impact on future agricultural productivity. The magnitude of the impact will depend on the contextual background, i.e. the needs and aspirations of farmers. Apart from that, the extent to which farmers can use adaptation methods to cushion themselves largely depends on their vulnerability to climate change.

The term vulnerability (to climate change) has been described differently by different authors. Paavola (2003) pointed out that vulnerability can be explained as the other side of adaptive capacity. This means the farmer is classified as vulnerable if they do not use their adaptive capacity for some reasons (natural or economic). Thus vulnerability will be reduced if they utilize effective adaptation methods. Another study by Madu (2012) in rural Nigeria, describes vulnerability to climate change as the extent to which society is unable to deal with the negative impacts of climate change. Houghton et al. (2001) in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report, defines vulnerability to climate change as the degree to which a system is unable to cope with the adverse effects of climate change. It has been noted that vulnerability of societies to the impact of climate change depends on the extent of climatic stress as well as the sensitivity and capacity of the society that has been affected. In this study we describe farmers' vulnerability to climate change as the state caused by the inability of a farmer to adjust to climate variability and change.

3.1.1 Vulnerability measures and Assessment

There are different approaches to assessing vulnerability. Deressa et al. (2009) assess household vulnerability to climate change in the Nile Basin of Ethiopia. They categorise vulnerability in three ways, namely; vulnerability as expected poverty, vulnerability as a low expected utility, and vulnerability as uninsured exposure to risk. The same categories are used by Hoddinott and Quisumbing (2003). Chaudhuri (2003) also describes vulnerability in terms of exposure to adverse shocks to welfare. Sarris and Karfakis (2006) use the Vulnerability as Expected Poverty approach in a study that compares rural household vulnerability in two regions in Tanzania, that is, Ruvuma and Kilimanjaro. They concluded that households living in poor regions are much more vulnerable than households in relatively affluent areas. That study identifies a vulnerable household as one which is expected to be poor in the future (regardless of current poverty situations) because of the adverse effect of climate variability.

Vulnerability as Expected Poverty (VEP)

This approach was developed by Chaudhuri et al. (2002) when assessing Indonesian households' vulnerability to poverty using cross-sectional data. Since then this approach has been used by many scholars, (see Christiaensen & Subbarao, 2004; Deressa et al,, 2009; Sarris & Karfakis, 2006; Tesliuc & Lindert, 2002). These studies argue that an individual is expected to be vulnerable if they will become poor in the future regardless of their current situation. In this concept, they assess household vulnerability by estimating the likelihood that a given stress will change the household's consumption pattern by either making it fall below a certain consumption poverty line (if household consumption is currently not falling below that minimum level) or forcing the household consumption level to remain below a minimum level (if household consumption is already below that level) (Chaudhuri et al., 2002).

Vulnerability as a Low Expected Utility

In this approach, the household is considered to be vulnerable if its utility is derived from consumption below a certain threshold; that is, below the point where an individual is not considered as vulnerable. Using panel data from Bulgaria, Ligon and Schechter (2003) define this category of vulnerability as the difference between the utility derived from a certain poverty line and the expected utility of consumption. In this case, Neumann-Morgenstern utility functions are used to measure utility and welfare losses (see Varian, 2006). This approach has a limitation in that it is very difficult to measure and quantify individuals' utility perceptions (Hoddinot & Quisumbing, 2008).

Vulnerability as Uninsured Exposure to Risk

This approach to measuring vulnerability focuses on the response of a household's consumption expenditures to various observable shocks. In this approach, probabilities are not constructed but rather welfare losses are assessed in relation to observed shocks (Skoufias, 2003). We can say that this method is a retrospective, ex-post assessment method (Hoddinot & Quisumbing, 2003).

Research suggests that socio economic and environmental factors may be among the important determinants of farmers' choice of adaptation methods in relation to climate change (Deressa et al., 2009). How all these factors affect farmers' income will be discussed in detail in the next chapter that analyses the factors affecting farmers' adaptation to climate change. The purpose of this chapter is to investigate the impact of these decisions on agricultural productivity and hence farmers' future welfare. The study assesses the advancement of vulnerability concepts by modelling human behaviour towards environmental change in Tanzania using the Vulnerability as Expected Poverty (VEP) approach. This approach is preferred to other approaches because it allows the use of a single cross-sectional dataset. The difference between the research of Sarris and Karfakis (2006) and this study is that this study uses a wide range of data covering four administrative regions which represent six of the seven agro-ecological zones in Tanzania. Therefore the results of this study may be generalized to the farming communities within the country with the exception of those in one agro-ecological zone not covered. Using this approach allows estimation of the extent to which different adaptation methods can reduce farmers' vulnerability and this may help farmers to choose the methods that are effective in reducing their vulnerability to climate change.

The remainder of this chapter is organized as follows: Section 3.2 briefly reviews the literature that discusses the issues of vulnerability to climate change. Section 3.3 describes the conceptual framework, variables used and data sources. It further specifies the models used in the vulnerability analysis. The results of the analyses are presented and discussed in section 3.4. In section 3.5 the conclusion and recommendations regarding the findings are presented.

3.2 Review of the empirical literature

This section reviews the existing literature on the factors contributing to farmers' vulnerability to climate change. It is expected that developing countries are likely to be more adversely affected by climate variability than developed countries. Thompson, et al. (2007) point out that change in climate has significant impacts on poor rural households who are dependent on agriculture. Depending on agriculture and being poor can make farmers susceptible to climate change because their adaptive capacity is limited. Thorlakson (2011) argues that smallholder farmers in developing countries fail to deal with climate change because there are costs involved in responding to these changes which are not affordable for them. Watson, et al. (1998) note that although vulnerable countries may show sensitivity[17] to climate change, their adaptability to this phenomenon is low.

Most developing countries, especially Sub-Saharan Africa countries, are believed to be more vulnerable to climate change not because the climate variability in Africa is greater, but because most of these countries' economies depend on rain-fed agricultural activities. Thus even a small amount of climate variability is likely to have a severe impact on crop harvests because when the crops are at high levels of temperature tolerance, a small increase in temperature will adversely affect the yield (IPCC, 1997). Similarly, change in rainfall from the required amount leads to reduction in agricultural output. Therefore, international organizations and local communities have been focusing on identifying strategies that they find to matter for smallholder farmers in dealing with the negative impacts of climate change so as to reduce their vulnerability (Morton, 2007).

Some climate change researchers (for example Adger, 2006; Chambers & Conway, 1991; Conway, 2009) argue that in order to reduce the probability of future poverty as a result of climatic shocks, there is a need to improve their general welfare. For smallholder farmers, who mainly depend on rain-fed agriculture, this can be done by introducing systems to help them to take advantage of the situation by adapting to climate change. This is in line with what Morton (2007) claims, that is, since agriculture remains the most important aspect of smallholder farmers' lives, it is very important to improve farming systems so as to take care of the negative impacts of climate shocks.

[17]Smit et al (2000) defined sensitivity as the degree to which a society is either affected or responsive to climate stimuli.

Some studies, while examining possible methods that might assist smallholder farmers to avert the negative impacts of climatic shocks, suggested that farmers can make use of drought resistant crops and improve flood preparedness (Fankhauser, et al., 1999; Smit, 2002; 2006). There are also studies that emphasise the importance of planting trees as one of the strategies that will help smallholder farmers to reduce the probability of them falling below the poverty line in the future (Challinor, et al., 2007; Verchot, et al., 2007; World Bank, 2008). Their argument is that, by planting nitrogen-fixing trees on their agricultural plots, farmers can provide nutrients to crops and hence enhance agricultural output.

To come up with a better policy to support adaptation to climate change, it is important to first look at the factors explaining farmers' vulnerability to climate change. After understanding the outcomes underlying vulnerability, we can address strategically effective adaptation methods that help reduce farmers' vulnerability.

Household characteristics are very important factors in reducing household vulnerability. A study conducted by Jha and Dang (2008) in selected countries in Central Asia revealed that in Azerbaijan, Kazakhstan, Kyrgyzstan, and Tajikistan households that are headed by females have less probability of falling below the poverty line in the future compared to households that are headed by males. The same results are found in Christiaensen and Boisvert (2000) for households in Mali. The argument is that female headed households engage more with the community and therefore are recipients of the effects of community solidarity which ensures they receive community help in times of need which will prevent them from becoming poorer.

The role of education should also be considered in an analysis of vulnerability. It is believed that an educated household head can better deal with ex-post risk. However, Chaudhuri, et al. (2002) discovers a negative relationship between levels of schooling and vulnerability for Indonesian communities. Comparing urban and rural areas, the study reveals that vulnerability for urban households with household heads without formal education is higher than the vulnerability for rural households with household heads without formal education. This is because the urban households have lower levels of mean consumption. The same results were revealed in studies of Nigeria (Alayande & Alayande, 2004) and Brazil (Ribas & Machado, 2007).

Another variable that has been mentioned in vulnerability studies is access to financial credit. Studies conducted in India (Bali Swain & Floro, 2008) and Bangladesh (Zaman, 1999) conclude that access to financial credit is a fundamental factor in reducing a household's and women's vulnerability respectively. The argument in Zaman's study is that if a woman has access to credit she has more control over her assets. The woman's control over the assets is gained after borrowing enhances her status in the society and hence it has an impact on reducing her vulnerability. Deressa, et al. (2009) identified the factors influencing farmers' vulnerability in the Nile basin in Ethiopia as household heads' income levels, the agro ecological setting, access to support from agricultural extension officers, and access to credit.

There are some studies which associate reducing vulnerability to climate change with livestock ownership. Ligon and Schechter (2004), for example, argue that farmers' households in Bulgaria that own a large number of livestock are less likely to become poor in the future. However the opposite relationship was found for West Africa (Fafchamps, et al., 1998). The argument of Fafchamps et al is that in the presence of drought shocks it is firstly, very difficult to handle large numbers of livestock. Secondly, they may be difficult to sell, especially when the markets for grains and livestock are well integrated. This occurs when prices among related goods follow similar patterns over a long period of time. Groups of prices often move proportionally to each other and when the similar pattern of prices is shown among markets of related goods, it is said that the markets are integrated. Thus, this explains how much the market for grains and livestock are related to each other and therefore can affect the sale of livestock in the presence of drought. The argument in the study by Ligon and Schechter is that farmers with large number of livestock can easily sell some of the animals in order to deal with the risks they are facing. Here large numbers of livestock act as insurance in relation to risks associated with climate change.

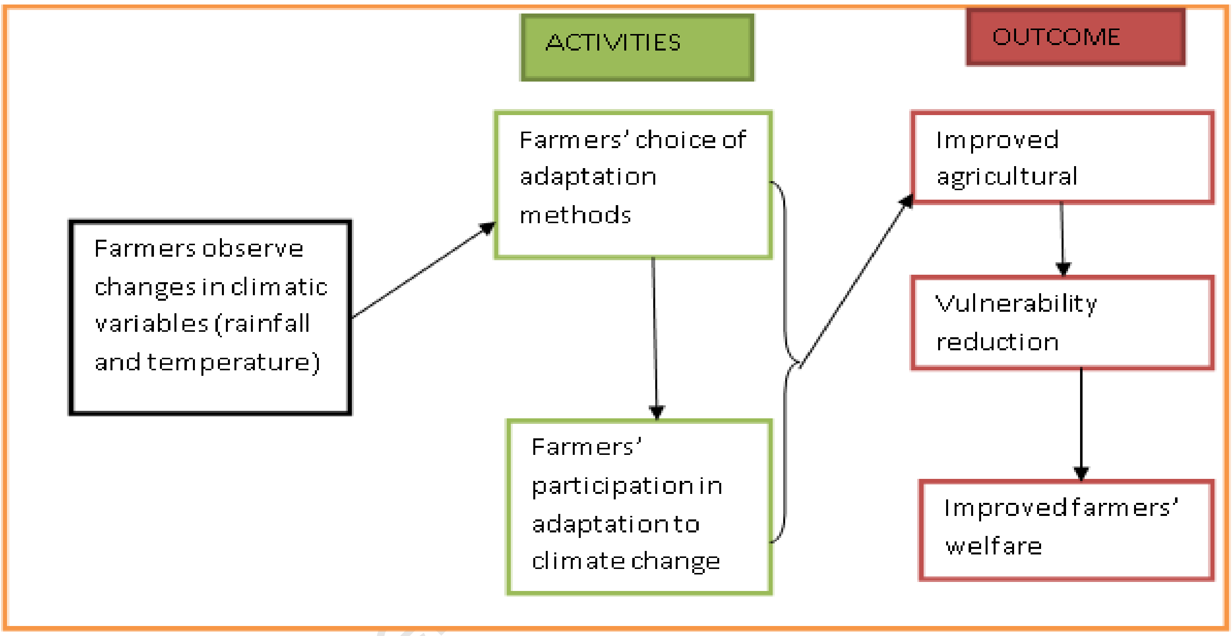
When comparing the vulnerability of rural farm households in two regions of Tanzania, Sarris and Karfakis (2006) find that major drivers of vulnerability include covariate shocks associated with climate change. Other studies with related results are from Tesliuc and Lindert (2002) for Guatemala, Makoka and Kaplan (2005) for Malawi, and Hoddinott (2006) for Zimbabwe. In Tesliuc and Lindert (2002), it is revealed that the effects of natural disasters and agricultural related shocks are felt far more within poor households. The same results were found by Makoka and Kaplan (2005) when studying Malawian subsistence farmers' vulnerability to droughts. However, in Hoddinott (2006) the results reveal that when there is a drought shock, households in Zimbabwe not only lose their assets but also experience serious health problems, especially women and children. The argument for health variables in measuring vulnerability is that when household members are healthy the probability of the household being vulnerable to climate change is reduced.

This current study examines the factors explaining farmers' vulnerability to climate change. This study also contributes to the literature by analysing vulnerability in different agro-ecological zones since it is known that diverse zones differ with regard to climate variables (rainfall and temperature) and it is these variances that differently affect the vulnerability of households in different zones. The starting point of this investigation is the identification of the following variables from the literature which play a role in vulnerability to climate change: access to credit, availability of capital, availability of water for irrigation, farmers' income, type of agro-ecological zone, education level and gender of the head of household, livestock ownership, and access to fertile land.

3.3 Conceptual and Analytical Framework

Theoretically, improvement of farmers' welfare leads to reduction of farmers' vulnerability. This study assumes that farmers can deal with the negative impacts of climate change by choosing one or more of the available adaptation strategies. In this case, it is expected that the choice that farmers are going to make to adapt to the shocks that result from climate change will lead to improvement in farm production, which in turn will increase farmers' welfare and hence reduce their vulnerability. However, the achievement of this objective depends on the characteristics of the farmer and on how the adaptation methods translate into agricultural activities. According to Füssel and Klein (2006:307), farmers can be "Dumb (that is, they do not adapt to climate change), Typical (adjust their management practices only), Smart (adjust to predicted climate conditions using existing information), or Clairvoyant (implement adaptation measures based on perfect foresight of future climate conditions)" depending on the efficiency of adaptation strategies they choose.

This study uses the Füssel and Klein (2006) augmented adaptation policy assessment model to investigate the role of farmers' choice of adaptation methods in increasing farmers' welfare and reducing their vulnerability. The adaptation policy assessment's target is to avert avoidable impacts of climate change by changing farmers from being "typical" to being "smart". A further study by Schipper (2007) identifies an "Adaptation Approach" to development, whereby society adapts in order to respond to the observed and experienced negative impacts to climate change (Adaptation to climate change impacts → Vulnerability reduction → Development). In this assessment, farmers are expected to adapt to climate change after observing the changes in climatic variables (in his case, changes in the amount and pattern of rainfall and temperature) and experiencing adverse impacts. These adaptations should ensure they attempt to reduce their vulnerability to climate change. By reducing their vulnerability it is clear that farmers can reduce the risks that are brought about by climate related hazards and therefore can experience more sustainable development. This assessment requires detailed observation of the response options that are feasible and available to farmers. The choice of adaptation methods depends on farmers' capability and the feasibility of implementation. If the farmers' adaptive capacity is effective, it is expected that there will be a decline in vulnerability to climate change.



Source: Author's own framework

Figure 3.1: Conceptual framework

This study utilises the approach by Chaudhuri, et al. (2002) aimed at estimating vulnerability and explaining how vulnerability is reduced using adaptation methods. The study employs the Vulnerability as Expected Poverty approach to capture the effect on vulnerability and it uses some of the variables which are found by Deressa, et al. (2009) to matter in reducing farmers' vulnerability. Deressa, et al. employ this approach in their empirical model of assessing household vulnerability to climate change[18] . Here, we are taking into consideration that being vulnerable does not mean the possibility of maintaining the status quo; it means the

[18] To investigate the impact of the choice of adaptation methods in reducing future vulnerability, this study includes the dominant adaptation methods used by different farmers.

probability of the household falling below the poverty line in the future as a result of climate variability even if the household is currently well-off.

3.3.1 Description of Variables and Data Sources

This study uses a survey dataset collected from 556 randomly selected farmers' households from December 2010 to January 2011 in four administrative regions of Tanzania namely; Iringa, Morogoro, Dodoma, and Tanga. These four were expressly chosen out of 26 regions in order to include most of the agro-ecological zones and therefore climate change impacts in Tanzania. The four selected regions represent six of the seven agro-ecological zones in Tanzania, as reported in United Republic of Tanzania (2007): coastal, arid, plateau, southern highlands, alluvial plains, and semi-arid.[19] This is a sample survey with a cross-sectional design. The units of analysis were drawn from the lists of households provided by "Nyumba Kumi" leaders[20]. The sample was randomly selected from the lists of eligible farmers' households as provided by the leaders. Data was collected from farmers using a structured questionnaire and face-to-face interviews during a two month field trip to the above mentioned regions. During the process, participation was voluntary and ethical considerations were taken into account with the farmers being assured of the confidentiality of the information they revealed. The respondents in the study were selected if they fulfilled three main conditions: (1) the household head is a smallholder farmer, that is, they own farming plots of not more than three hectares (Montiflor, 2008; Eicher, et al., 2006), (2) the household head is aged 18 years and above[21], and (3) the household head's major economic activity is agriculture. The interview was carried out in Kiswahili which is the Tanzanian national language and is spoken by the majority of Tanzanians.

Most importantly, farmers were asked to compare the climate between the decades of the 1990s and 2000s with respect to mean and variance precipitation and temperature and were asked if they had observed changes. They were later asked about the ways in which they had responded to the perceived climate changes. Here, farmers were asked to mention the methods

[19] There is a need for diversity in order to get a good proxy for climate change so that the results obtained from the study can be generalized to the rest of the country.

[20] In Tanzania there is a "Nyumba Kumi" concept whereby households within ten neighbouring houses group together under one leadership which is recognised by the government. The leaders in the groups know almost all members of their groups; their ages, activities and so on.

[21] A household with a household head less than 18 years of age is not included because it thought that those household heads are minor. Moreover, since this study is about climate change and it requires household heads to remember the changing climatic variables for the past 20 years, we thought it will be very difficult for them to remember what happened during their childhood.

they had used in the last decade to respond to the perceived climate change. About 34 percent of surveyed farmers did not undertake any adaptation strategies. For those farmers employing adaptation methods, the dominant methods reported to be used were planting short season crops (134 farmers, 24.1 percent), planting crops resistant to drought (96 farmers, 17.3 percent), changing planting dates (63 farmers, 11.3 percent), planting trees (41 farmers, 7.4 percent), and irrigation (31 farmers, 5.6 percent).[22]

To estimate vulnerability using the Vulnerability as Expected Poverty approach (VEP)[23], the study uses per capita farm income[24] as a dependent variable. Reilly and Schimmelpfennig (1999) point out that a farmer has a high probability of suffering the negative effects of climate variability if they have insufficient financial resources and adaptive technological opportunities[25]. This study assumes that farmers do not have any other income and they use only farm income for consumption as well as financing agricultural activities including adapting to climate change[26]. The study uses the VEP approach because the assumption is made that if the farmers' poverty level is expected to increase in future, then they will not be in a position to choose effective adaptation methods to cope with climate change. As a result agricultural production will decrease further, consistent with future farm income.

[22] Given that farmers may have several plots on which they might employ different adaptation measures, each farmer was assigned their dominant adaptation method in the investigation based on the factors influencing choice of adaptation methods to climate change. Thus, for example, if a farmer has a total of 3 hectares and uses different adaptation methods to deal with climate change, say, by planting short season crops on 1.5 hectares, irrigation on 1 hectare, and planting trees on 0.5 hectares, the planting of short season crops was assigned as the dominant adaptation method. Each adaptation method dummy is assigned 1 whenever a farmer implements that as a dominant adaptation method and 0 otherwise. The type of adaptation methods included in this study are irrigation, changes in planting dates (i.e. early or late planting depending on availability of rainfall); planting crops which are resistant to drought; planting the same crop but different varieties (e.g. short season instead of long season maize); and planting trees across farms.

[23] Chaudhuri, et al. (2002), Sarris and Karfakis (2006) and others measured vulnerability in terms of consumption but this study uses per capita farm income as applied in Deressa, et al. (2009). In this study the variable was computed by taking the annual farm income that has been reported by the farmer divided by the number of the members of the household.

[24] Farm income includes the value of farm products used for household consumption in a year.

[25] Reilly and Schimmelpfennig (1999) identify this as farmer or farm sector vulnerability

[26] The statistics in this study reveal that 187 out of 556 farmers' households do not have any other income apart from farm income, while 520 households have less than TZS. 1,000,000 per year. This amount is very little to cover even the food stuff in the household in a year. The statistics further disclose that farm income contributes about 88.9% of farmers' total income, in this case, only 11.1% of their income comes from non-farm activities. Moreover, farm income can directly be affected by climate change. Therefore it is reasonable for the assumption to hold.

Independent variables

This study identifies socio-economic variables relevant to the choice of adaptation strategy. These include: Age of the head of household, gender of the head of household, household size, farm size, highest education level of the household member, livestock ownership, and the dominant adaptation method used by the farmer. Socio-economic variables are important in explaining farmers' vulnerability. Farmers' households in more favourable situations are expected to be less vulnerable compared to those that are less well off. In this case therefore, farmers' vulnerability is an outcome of unfortunate socio-economic status.

The ages of household heads range between 18 and 96 years, the average age being 46.2 years. This is in line with the average household head age in Tanzania where the average age is 46.3 years (World Bank, 1999). The average number of the household size is 6.45 people which is slightly higher than the average of 4.8 members in Tanzania (UNFPA, 2013). The highest education in the household on average is 10 years. This is more than primary school education that is offered for 7 years in Tanzania. This means at least a good number of households have members with more than primary school education. More than half of the households are headed by males i.e. 76 percent. As previously mentioned, the study concerns smallholder farmers with not more than 3 hectares. On average the households own 1.9 hectares of farm land.

Environmental variables used in the study include: A dummy variable created for whether the farmers reported observing droughts and floods within the period of twenty years, location of agricultural plots, and average rainfall and temperature in the households' neighbourhood in 2010. In this study, environmental factors are also important in explaining vulnerability to climate change. Changes in rainfall and temperature above or below the amount suitable for agriculture reduce agricultural output and farm income and therefore increase farmers' vulnerability. The statistics reveal that the average rainfall in the neighbourhood is 875.1 mm while the average temperature is 24 degrees centigrade. 71 percent of farmers' households reported experiencing floods in the past 20 years while 87 percent of households reported experience of drought. Very few agricultural plots are located in Semi-arid, Plateau, and Southern highlands agro-ecological zones. This might be because of the soils and topography characteristics as presented in table 1.1. In general those areas are characterized by infertile sands, dissected hills and mountains, and rocky hills. The statistics show that only 6 percent of farmers use irrigation as their dominant adaptation method. This is not surprising as the reality indicates that 95 percent of agriculture in Tanzania is rain-fed (Hepworth, 2010).

Economic factors have also been included in this study because of their importance in explaining the impact of economic structures on the welfare of farmers. In this study economic structures include market conditions and economic alternatives (for example, access to formal and informal credit[27], and distance from inputs and/or output markets) which promote agricultural productivity. Access to credit, whether formal or informal, helps farmers to finance adaptation methods and reduce the probability of their earnings falling below the poverty line in the future. Forty eight (48) percent of farmers' households in the sample reported to have access to either formal or informal credit. The cost of buying inputs and selling outputs increases in relation to distance from markets. This reduces the farmers' income obtained from agricultural products and increases their vulnerability. On average, households reside about 5.65 kilometres from input/output markets. Statistics of the variables included in the model are presented in the table below:

Table 3.1: Descriptive statistics of the variables

Variable	Mean	Std. Dev.	Min	Max
household per capita farm income per day (Tshs)	2556.71	2681.77	316.12	30136.99
Age of the head of household (Years)	46.20	12.73	18	96
Head of household is male (Male=1, female=0)	0.76	0.43	0	1
Highest education in the household (number of years)	10.19	3.07	0	19
Has received agricultural technical support from community group or government (yes=1, no=0)	0.57	0.49	0	1
Size of the household (number)	6.45	3.47	1	17
Farm size (hectares)	1.92	0.76	0.5	3
Experienced flood in the past 20 years (yes=1, no=0)	0.71	0.44	0	1
Experienced drought in the past 20 years (yes=1, no=0)	0.87	0.34	0	1
Average rainfall in household's neighbourhood in 2010 (mm)	875.10	251.10	583	1370.7
Average temperature in household's neighbourhood in 2010 (^{0}C)	24.10	2.34	21	27.07
Grows maize as the major crop (yes=1, no=0)	0.49	0.50	0	1
Grows rice as the major crop (yes=1, no=0)	0.06	0.24	0	1
Grows sorghum as the major crop (yes=1, no=0)	0.12	0.33	0	1
Access to credit (yes=1, no=0)	0.48	0.50	0	1

[27] This takes the value 1 if a farmer has access to either formal or informal credit and 0 otherwise

Variable	Mean	Std. Dev.	Min	Max
Distance from output markets (kilometres)	5.65	4.39	0.5	11
Uses short season crops (yes=1, no=0)	0.35	0.48	0	1
Uses crops resistance to drought (yes=1, no=0)	0.17	0.38	0	1
Uses irrigation (yes=1, no=0)	0.06	0.23	0	1
Plants trees (yes=1, no=0)	0.07	0.26	0	1
Located in the Coastal agro-ecological zone (yes=1, no=0)	0.27	0.44	0	1
Located in the Arid agro-ecological zone (yes=1, no=0)	0.23	0.42	0	1
Located in the Alluvial agro-ecological zone (yes=1, no=0)	0.26	0.44	0	1
Located in the Southern highlands agro-ecological zone (yes=1, no=0)	0.07	0.25	0	1
Located in the Semi-arid agro-ecological zone (yes=1, no=0)	0.09	0.29	0	1
Located in the Plateau agro-ecological zone (yes=1, no=0)	0.07	0.25	0	1

Data sources:

(i) an interview-based survey from Iringa, Morogoro, Dodoma and Tanga regions December 2010 – January 2011

(ii) Tanzania Meteorological Agency (TMA); January, 2011

3.3.2 Model Specification

The choice of adaptation methods implemented by the farmer is identified as one of the factors that lead to a fall in the farmers' future income below the poverty line as a result of climate variability. The distribution of the farm income needs to be considered in an investigation of adaptation methods, because estimates for vulnerability require a normal distribution. Accordingly, per capita farm income was transformed to its logarithmic form. Therefore, per capita farm income is log-normally distributed[28] and captured by the mean and variance. Thus, variance of future per capita farm income is also estimated. Usually, the variance of the error term is assumed as the prediction stems from measurement errors and is assumed equal for all households. Two models were used in this study. The first one is for a vulnerability assessment that allows estimation of the vulnerability score for every household.

[28] The study tested the assumption that farm income is log-normally distributed using the Shapiro-Wilk normality test. The null hypothesis is that farm income is normally distributed. The test results fail to reject the null hypothesis that farm income is normally distributed with W = 0.99571 and P = 0.13235. In this case the assumption that farm income is log-normally distributed holds.

The second model is the binary logit model that analyses the probability of the households falling below the poverty line in the future.

When estimating farmers' vulnerability, it is assumed that the error term is not only a measurement error, but also interpreted as the inter-temporal variance of log farm income. In this case, it captures idiosyncratic and covariate shocks faced by a farmer. As idiosyncratic shocks differ from household to household, it is not appropriate to assume the same variance for all households. In this case, one needs to assume that the model underlies heteroskedasticity. In the existence of heteroskedasticity, the regression estimator is no longer BLUE (Best Linear Unbiased Estimator), but in estimating vulnerability the study is interested in the differences of variance. To get rid of heteroskedasticity, the variance of the error term will depend upon the particular characteristics of the farmer. This can be done by using the three-step Feasible Generalized Least Square (FGLS) method as suggested by Amemiya (1977).

Vulnerability assessment

The study defines a farmers' vulnerability as a situation where farmers find themselves below the poverty line in the future regardless of whether they are currently poor. That is, it is the probability that the future income of a farmer, who currently has limited financial resources to deal with negative effects of climate variability, will go below a certain ex ante poverty line, say z (Chaudhuri 2002)[29]:

$$v_{f,t} = p(I_{f,t+1} \leq z) ----------------(3.1)$$

where $V_{f,t}$ is farmers' vulnerability to climate change, $I_{f,t+1}$ is a farmers' future farm income.

As has been mentioned above, vulnerability can lead to a deterioration in farmers' welfare due to adverse shocks. Farmers operate in environments characterized by idiosyncratic risks and covariate risks such as weather related (drought and flood) risks and price fluctuations. These shocks affect the level and variability of the household's endowments. In the face of these risks, households allocate their endowments to a portfolio of activities, each generating

[29] The study uses \$1 as a threshold because (i) it is an internationally defined poverty line (Gustafsson & Li, 2004; Kamanga, et al., 2009; Figini & Santarelli, 2006); and (ii) it assumes that if a farmer cannot have at least that amount of total income then it will be very difficult for them to adapt. Below this income level the farmer is considered to be vulnerable.

income. Nevertheless, income often fluctuates in response to shocks depending on portfolio configuration. However, under normal conditions, we may not map changes in income and consumption on a one to one basis because households usually try to cushion their consumption from income shocks through ex-post consumption smoothing behaviour. Tanzanian small scale farmers smooth their income to reduce their exposure to risk through adapting to climate shocks. It follows that, the level and variability of a household's future consumption stream hinges on the stochastic nature of the risk factors, the degree to which these affect household income (that is, its risk exposure) and the ability of the household to protect its consumption from income shocks (that is, its coping capacity). In this study, a measure of the vulnerability of a farmer is obtained by predicting farm income levels either by varying the values of X_f[30] or by varying the values of β. The impact of climate variability is simulated by estimating equation (3.2) but replacing mean rainfall/temperature levels with those below the mean, calculating expected farm income levels for all farmers and comparing this against the poverty line. As stated by Chaudhuri (2003), farmers' income derived from farm output is a stochastic variable depending on the dominant adaptation method chosen by the farmer, the climate variability shocks, and other variables, as previously explained.

$$\ln I_f = X_f \beta + \varepsilon_f ---------------- (3.2)$$

where I_f is the dependent variable (farmers' income derived from farm output), β's are partial regression coefficients, X_f's are independent variables, and ε_f is the disturbance term.[31]

Given the fact that the study is using cross-sectional survey data, it is necessary to make two important assumptions; (a) for each household, the idiosyncratic shocks to the income derived from farm output are identically and independently distributed over time; and (b) in order to rule out the possibility of an aggregate shock, the structure of the economy captured by partial regression coefficients is assumed to be fixed in a given range of time (Jamal, 2009). Thus the uncertainty about idiosyncratic shocks (the disturbance term) will be the only factor leading to

[30] These are independent variables used in the analysis.

[31] ε_f contains all factors that affect farmers' farm income other than those captured in the mode.

uncertainty about future farm income. The variance of the disturbance term is also assumed to depend on the set of independent variables, including household characteristics (X_f); that is,

$$\sigma_{t,f}^2 = X_f \theta ----------------------------------(3.3)$$

After estimation of equation (3.2) using Ordinary Least Squares (OLS) and equation (3.3) using the squared residuals predicted from (3.2) as regressands, we can now estimate farmers' vulnerability to climate change. Chaudhuri (2003) pointed out that vulnerability is a non-linear function of a farmers' future consumption (in this case, farmers' future farm income). It is expected to depend on (apart from other things) two main factors: its mean, and the variance. The heteroskedastic specification (equations 3.4 to 3.6) combined with the explicit modelling of the shocks, allows the variance of each household's income to differ across households depending on their characteristics, the variance of the shocks the household faces and the differential effect of the shock on the household.

$$\hat{E}[\ln I_f \mid X_f] = X_f \hat{\beta} ------------------(3.4)$$

$$\hat{V}[\ln I_f \mid X_f] = \hat{\sigma}^2_{t,f} = X_f \hat{\theta} -------------(3.5)$$

This model follows that farmers' farm income is log-normally distributed. The expected mean and variance in equations 3.4 and 3.5 can be used to estimate the probability of observing the level of farmers' income fall below the poverty line given the vector of independent variables (X_f), a vector of unknown parameters (β), and the stochastic error term (ε_f). Amemiya (1977) suggest that the parameters for the expected log of farmers' farm income (β) and that of its variance (θ) can be obtained from the three-step feasible generalized least squares (FGLS) regression. The likelihood of observing the dependent variable (v_f) which is ($P(\ln I_f < \ln z | X_f)$) will be tested as a function of variables including dominant adaptation methods implemented by farmers, highest education level in the household, climate change variables, and other variables. The vulnerability score for every farmer is obtained and expressed as a probability that takes the values between 0 and 1 (1 implies highest vulnerability). Following Chaudhuri, et al. (2002) and assuming the cumulative distribution of ε_f is standard normal, the estimated probability is denoted by:

$$\hat{V}_f = p(\ln I_f < \ln z \mid X_f) = \Phi\left(\frac{\ln z - X_f \hat{\beta}}{\sqrt{X_f \hat{\theta}}}\right) ----------(3.6)$$

where $\Phi(.)$ is the cumulative density of the standard normal; p is the probability of observing a specific outcome of the dependent variable; β and θ are regression parameters to be estimated; X is a set of explanatory variables (specifically, $X_f \hat{\beta}$ are FGLS estimates of log farm income per capita; $\sqrt{X_f \hat{\theta}}$ are FGLS estimates of the error term; and lnz is the ex-ante poverty line).

Binary logit model: Probability of a farmer to fall below the poverty line

After estimating the vulnerability score for every farmer's household, the study assessed the characteristics of farmers' households that are likely to fall below the poverty line currently and in the future. This was done using the binary logit model. The model assumes that the cumulative distribution of ε_i is logistic[32]. The probability of the farmer falling below the poverty line is estimated using the logistic probability model specified as (Woodridge 2001):

$$P(Y=1 \mid X) = \Lambda(x'\alpha) = \frac{e^{x'\alpha}}{1+e^{x'\alpha}} --------------------------(3.7)$$

where Λ is the logistic cumulative distribution function, P(Y=1|X) is the probability of observing a farmers' household income falling below the poverty line and it depends on a vector of independent variables (x), unknown parameters (α).

This model implies a diminishing magnitude of marginal effects for the independent variables and the coefficients give the signs of the marginal effects of each of the independent variables on the probability that the farmers' household income will fall below the poverty line. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{N} I_i \ln[\Lambda(x'\alpha)] + (1-I_i)\ln[1-\Lambda(x'\alpha)] ------------------(3.8)$$

[32] The model assumes that the cumulative distribution of error term is logistic due to the fact that a logistic distribution has a shape similar to that of the normal distribution. This makes it convenient to replace the normal by the logistic in order to simplify the analysis.

where I_i is the dummy indicator equal to 1 if the farmers' household i income falls below the poverty line and 0 otherwise.

The consistent maximum likelihood parameter estimates are obtained by maximizing the above log likelihood function. The marginal impact for each variable on the probability level is given by:

$$\frac{\partial P(Y=1|X)}{\partial X_k} = \frac{\partial \Phi(Y=1|X)}{\partial X_k} = \Lambda(X'\alpha)[1-\Lambda(X'\alpha)]\alpha_k \text{------------}(3.9)$$

while the marginal effect for a dummy variable, say X_k, is the difference between two derivatives evaluated at the possible values of the dummy i.e. 1 and 0, Thus,

$$\frac{\partial P(Y=1|X)}{\partial X_k} = [\Lambda(X'\alpha)[1-\Lambda(X'\alpha)]\alpha_k]_{X_k=1} - [\Lambda(X'\alpha)[1-\Lambda(X'\alpha)]\alpha_k]_{X_k=0} \text{---}(3.10)$$

3.4 Results and Discussions

This section provides the estimations used to address the objectives of the study. This study, therefore (i) assesses the prospects of farmers in Tanzania being poor in the future due to climate change; (ii) investigates the characteristics of farmers who are vulnerable to climate change; (iii) estimates whether specific adaptations to climate change affect the prospects of farmers being poor; and (iv) evaluates the adaptation methods that are effective in reducing farmers' vulnerability to climate change for different agro-ecological zones.

3.4.1 The Analysis of Poverty and Vulnerability levels.

Table 3.2 presents farmers' household characteristics at the 0.5 vulnerability threshold[33].

[33] The vulnerability threshold of 50 percent is reasonable because it is logical to consider a farmer vulnerable if they have a chance of 50 percent and above of falling into poverty in the future. Chaudhuri, et al. (2002, 2003) and Pritchett, et al. (2000) also used 0.5 vulnerability threshold in their vulnerability studies. The study also uses a vulnerability threshold of 0.41 calculated using the Vulnerability Poverty Line (VPL) function provided by Pritchett, et al. (2000:7) by dividing the poverty rate chosen by the study of 1 USD (TZS. 1592) per person per day by average per capita farm income per day (TZS. 3936).

Table 3.2: Poverty and vulnerability levels within different segments of the population (Vulnerability threshold of 50% and poverty line = TZS. 1592

Current condition	Population share	Share of the poor (% of poor)	Poverty headcount (% within each group)	Share of the vulnerable (% of vulnerable)	Mean vulnerability	Vulnerability headcount (% within each group)	Vulnerability to poverty ratio
regardless of the initial condition	100.0	100.0	18.0	100.0	0.525	52.5	2.9
residence in agro-ecological zone							
Plateau	6.8	9.0	23.7	7.9	0.658	60.5	2.6
Alluvial	26.4	14.0	9.5	27.9	0.537	55.1	5.8
Semi-arid	9.5	1.0	1.9	9.0	0.547	49.1	26.0
Southern highland	6.8	6.0	15.8	7.2	0.526	55.1	3.5
Coastal	27.0	20.0	13.3	27.6	0.520	53.3	4.0
Arid	23.4	50.0	38.5	20.3	0.469	45.4	1.2
Observing shocks							
Have experienced drought	87.1	93.0	19.2	88.3	0.533	52.9	2.8
Haven't experienced drought	12.9	7.0	9.7	11.7	0.472	47.2	4.9
Have experienced flood	71.9	77.0	19.3	68.6	0.503	49.8	2.6
Haven't experienced flood	28.1	23.0	14.7	31.4	0.583	58.3	4.0
Household characteristics							
Small households (with five or fewer household members)	49.6	2.0	0.8	19.4	0.207	20.7	25.9
Medium households (with household members between 6 and 10 people)	36.5	41.0	20.2	55.8	0.808	80.8	4
large households (with more than 10 household members)	13.9	57.0	74.0	24.8	0.948	94.8	1.3

Male headed households	75.7	71.0	16.9	76.9	0.539	53.0	3.1
Female headed households	24.3	29.0	21.5	23.1	0.482	49.6	2.3
primary school education	36.5	36.0	17.7	35.9	0.503	51.2	2.9
more than primary sch. education	63.5	64.0	18.1	64.1	0.538	52.7	2.9
Households with non-farm income	66.4	76.0	20.6	69.0	0.553	54.2	2.6
Households without non-farm income	33.6	24.0	12.8	31.0	0.471	48.1	3.8
Received agricultural support	57.4	63.0	19.7	57.6	0.524	52.4	2.7
Do not receive agricultural support	42.6	37.0	15.6	42.4	0.536	51.9	3.3

Note:

- *The number of poor people is 100 while the number of vulnerable is 292*
- *The fraction of poor people is the poverty headcount ratio*[34].
- *The fraction of those who are vulnerable is the vulnerable headcount ratio, or the share of persons with a vulnerability threshold of more than 50 percent.*
- *Mean vulnerability is the mean probability of being poor in the future of a particular group (the mean of the vulnerability index for the persons in the group).*
- *Authors' calculations using study survey data (December 2010 – January 2011)*

[34] The study calculated poverty using poverty headcount following (Gustafsson & LI, 2004; Park & Wang, 2001).

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The results reveal that when the survey was conducted, 18 percent of the surveyed households were poor. The results also reveal that almost 52.2 percent of the surveyed households had more than a 50 percent chance of falling into poverty in the future. This is the group that is vulnerable to climate change. There are differences between the poverty and vulnerability rates. While the poverty rate is the percentage of farmers' households that are considered to be currently poor, the vulnerability rate is the percentage of farmers' households that are likely to fall below the poverty line in the future (vulnerable households). A higher vulnerability to poverty ratio shows a more dispersed distribution of vulnerability among the households, while a lower ratio means that vulnerability is concentrated among a few households. Overall, the number of vulnerable households is 3 times higher than the number of poor households. Within some groups, this difference is exceptionally high.

The poverty headcount reveals that farmers that reside in the arid agro-ecological zone have the highest share of poor households (38.5 percent of all households in the arid area), followed by farmers in the Plateau zone, with 23.7 percent of these households being poor. In third place with regard to current poverty, are farmers from the Southern highlands (15.8 percent). As for the vulnerability headcount results, farmers that reside in the Plateau zone are shown to be more vulnerable, with 60.5 percent of households expected to be poor in the future. With regard to mean vulnerabilities, the Alluvial, Semi-arid, Southern Highlands and Coastal zones have 0.54, 0.55, 0.53 and 0.52 respectively; while those in the Plateau zone are still ahead with 0.66; and those in the Arid zone are last with 0.47. The results in all six agro-ecological zones show that there are more vulnerable households than poor households. This also reflects the vulnerability to poverty ratio, which is 3 for the whole sample. The vulnerability to poverty ratio shows that there are more households that are vulnerable than poor in the Semi-arid zone (with the ratio of 26) but there are very few household that are more vulnerable than poor in the Arid zone (with the ratio of 1.2). In this case, policy interventions that will promote effective adaptation strategies for the farmers' households residing in the Semi-arid zone are to be encouraged.

Other interesting findings are shown by assessing poverty and vulnerability levels in relation to different household characteristics. Table 3.2 also shows that large households (with more than 10 household members) seem to be not only currently poor with 74 percent, but also vulnerable with 94.8 percent. A very large household would increase consumption thus reducing the possibility of savings and increasing susceptibility to poverty. The vulnerability to poverty ratio for large households is 1.3 and for small households is 25.9. This means that there are 1.3 times more vulnerable than poor large households and almost 26 times more vulnerable than poor small households.

Twenty one point five (21.5) percent of female headed households are poor and 49.6 percent of these households are vulnerable. In comparison to female headed households, male headed households are more likely to become poor in the future, with a vulnerability headcount of 53 percent. Surprisingly, the comparison of the households with different mean education levels shows that households with more than primary school education are clearly more vulnerable to poverty with a vulnerability headcount of almost 53 percent and a vulnerability to poverty ratio of 2.9. Another surprising result is obtained by comparing the poverty and vulnerability of farmers with and without non-farm income. The results reveal that farmers with non-farm income are poorer and more vulnerable compared to their counterparts, with vulnerability and poverty headcounts of almost 54 percent and 20.6 percent , respectively.

The study also compared farmers' households who have received agricultural support from either the Tanzania Government through their agricultural officers or from other farmers. The results reveal that farmers who have received agricultural support are currently poorer but are less vulnerable with a vulnerability headcount of 52.4 percent and a vulnerability to poverty ratio of 2.7. The results reveal that farmers' households that have experienced the two natural shocks (drought and flood) are poorer. The study shows mixed results for vulnerability in this group. While farmers who reported experiencing floods seem to be less vulnerable compared to those who have reported not to experience floods, it is also revealed that farmers who reported experiencing droughts are more vulnerable, with a vulnerability headcount of almost 53 percent.

3.4.2 Scatter-plots for vulnerability analysis

Following the methods discussed in section 3.3.2, the study has estimated households' vulnerability levels, that is, the probability of a household falling below a certain farm income (poverty line) in the future. The vulnerability index takes the values between zero and one. The minimum level of income was chosen based on certain assumptions. In this study, it is assumed that, if each member of the household can be sure of having 1 USD per day then that household is not poor. In Tanzanian shillings, this minimum income level translates to TZS. 1592. The scatter-plots presented in figures 3.2 and 3.3 reveal the vulnerability score for every household, plotted against the natural log of household daily per capita income from the farm.

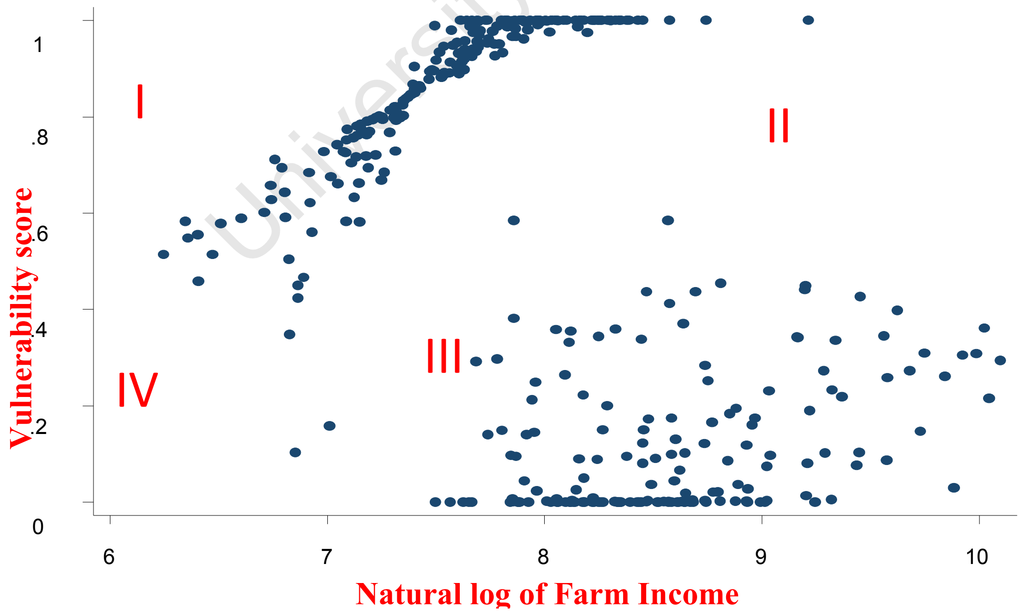
The vertical line (y-axis) displays computed vulnerability. Figure 3.2 shows that, the households are divided into low and high vulnerability levels using 0.5 (fifty percent) as a vulnerability threshold. Households that fall above the 0.5 line are classified as highly vulnerable while those that fall below the 0.5 line are the less vulnerable households. Figure 3.3 uses a vulnerability threshold of 0.41 (41 percent) with the same interpretation that households that fall above 41 percent are highly vulnerable, regardless of their current poverty status. As for the poverty measure, which is the horizontal line (x-axis), both figures use the poverty level of TZS. 1591 (natural log of farmers' income derived from farm output = 7.3727) as a cut off.

The scatter-plots are divided into quadrants. The two parts which are above the 0.5 (for figure 3.2) or 0.41(for figure 3.3) vulnerability thresholds show households that are highly vulnerable. The households in quadrant I are revealed to be poor now and are likely to remain poor in the future, while quadrant II shows the households that are currently not poor but are likely to be poor in the future. The households in the lower side of the plots have the lowest vulnerability scores; that is, they are considered to have a less than 50 percent (or 41 percent) probability of becoming poor in the future. Quadrant III displays the households that are currently below the poverty line but are not expected to be poor in the future and those in quadrant IV are currently not poor and are likely to remain above the poverty line in the future.

Both scatter-plots illustrate that, for households that are above the vulnerability threshold, there is a positive relationship between the level of vulnerability (expected to be poor in the future) and the farmers' income derived from farm outputs. That is, regardless of their current poverty condition, the vulnerability level increases as per capita farmers' income derived from farm output per day increases. Generally, both scatter-plots display that, within the low income households there are more vulnerable households. As for high income households, the scatter-plots show two distinct groups, though less vulnerable households are in the majority. It is expected that poor households will be more vulnerable because their adaptive capacity is low. As for non-poor households, the ones that are vulnerable to climate change might be so because the adaptation methods they chose and implement are ineffective.

Source: *Own survey data, December 2010 – January 2011*

Figure 3.2: Vulnerability threshold of 50 percent



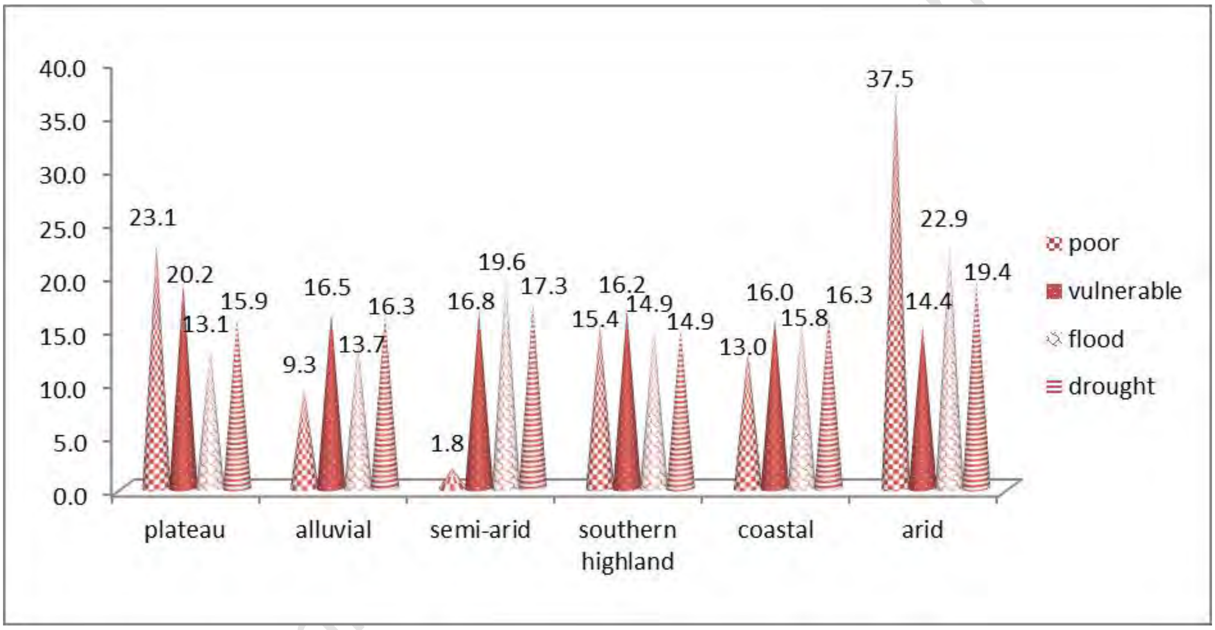
Source: *Own survey data, December 2010 – January 2011*

Figure 3.3: Vulnerability threshold of 41 percent

3.4.3 Who are mostly affected by shocks and most likely to be affected?

The following figures investigate the relationship between shock incidence (the occurrence of floods and droughts as observed by Tanzanian farmers for the past 20 years) and household characteristics for those shocks using the surveyed data collected by the researcher from six agro-ecological zones in Tanzania. Most farmers reported having witnessed these two major shocks that seriously affect their agricultural output.

Figures 3.4 to 3.8 illustrate the relative incidence of these shocks (the percentage of the population who have experienced these shocks), the proportion of the population that is currently affected by the shocks (poor people) and the proportion of the population that is expected to be poor in future.

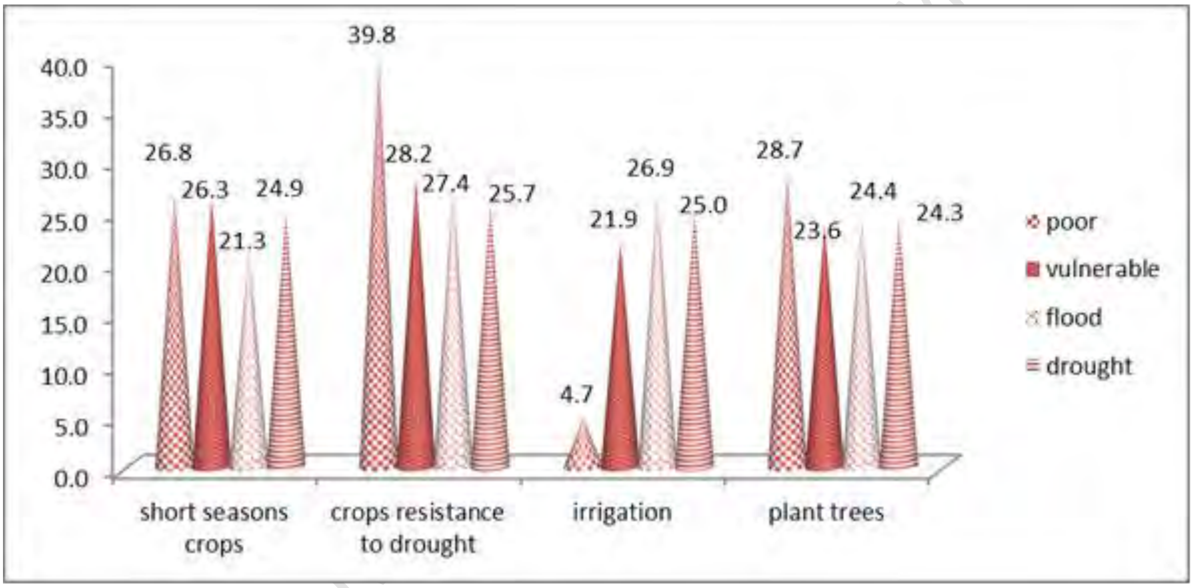


Source: *Own survey data, December 2010 – January 2011*

Figure 3.4: Poverty, vulnerability and shocks by zone

Figure 3.4 shows the effects of observed shocks by agro-ecological zones in which the farmers reside. The results show that 484 households experienced drought in the past 20 years. The results further reveal that 19.4 percent of the households which experienced drought in the past 20 years reside in the arid agro-ecological zone, 17.3 percent are farmers residing in the Semi-arid agro-ecological zones and 16.3 percent each are farmers' households residing in the Alluvial and Coastal agro-ecological zones. Four hundred (400) farmers' households experienced flood in the past 20 years, 22.9 percent of which reside in the Arid agro-ecological zone. 19.6 percent and 15.8 percent of households which experienced flood reside in the Semi-arid and Coastal agro-ecological zones respectively.

For the farmers who are currently reported as poor (that is, living below 1 USD per household member per day), the results reveal that almost 38 percent reside in the Arid agro-ecological zone, 23.1 percent of farmers that are poor reside in the Plateau agro-ecological zone. Only 1.8 percent of farmers' households that are observed to be currently poor reside in the Semi-arid agro-ecological zone. The largest proportion of farmers who are expected to be poor in the future reside in the Plateau zone (20.2 percent) followed by farmers' households that reside in the Semi-arid zone (16.8 percent). These results tell us that special attention should be given to farmers residing in the Plateau and Semi-arid zones because they are the ones who are most likely to be vulnerable to the effects of climate change. Appropriate adaptation methods to climate change should be introduced and practised by farmers in those zones to reduce their vulnerability.



Source: *Own survey data, December 2010 – January 2011*

Figure 3.5: Poverty, vulnerability and shocks by chosen adaptation strategy

In figure 3.5 shocks are observed by the dominant adaptation strategy used by farmers. Twenty five point seven (25.7) percent of farmers' households that reported to experience drought in the past 20 years use crops that are resistant to drought to adapt to climate change, 25 percent and 24.9 percent of the farmers respectively chose irrigation and short season crops as the method to reduce the negative effect of climate change. Among the farmers who have experienced flood in the past 20 years, 27.4 percent use the crops that are resistant to drought, 26.9 percent irrigate and 24.4 percent plant trees in their plots in order to reduce the negative impact of climate change.

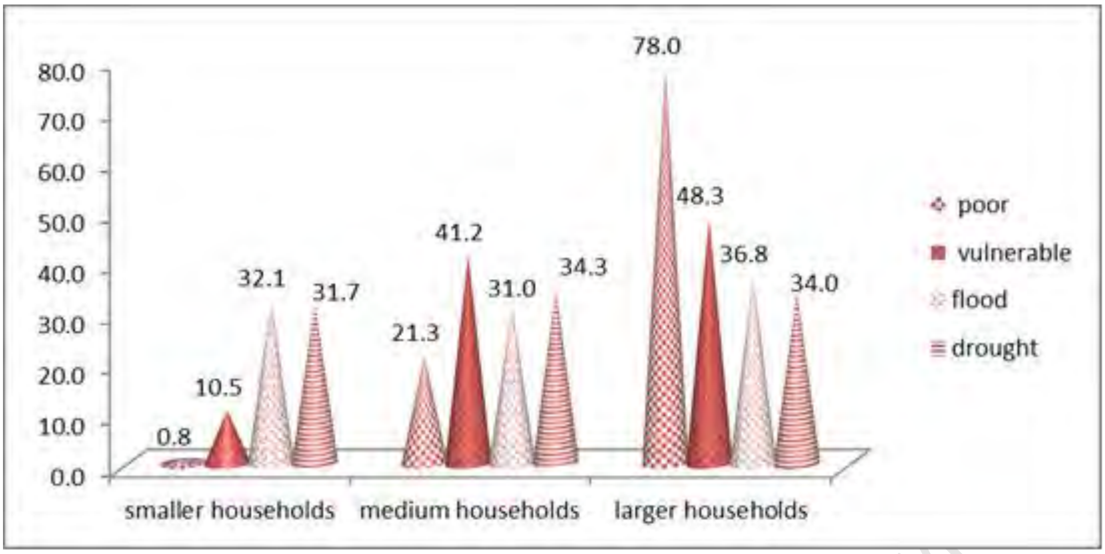
As for currently poor farmers, the results show that almost 40 percent of poor household plant crops that are resistant to drought. Farmers who use short season crops as their dominant adaptation strategy number 26.8 percent. Only 4.7 percent of the farmers' households who are currently poor can afford to irrigate their farms. Among the farmers' households that are classified as vulnerable, 28.2 percent of the households that are observed to fall below the poverty line in the future use crops that are resistant to drought in adapting to climate change. Apart from these, almost 23.6 percent of the households opt to use short season crops and 18.8 percent plant trees as their dominant adaptation technique to deal with the negative impacts of climate change.

As the results reveal, many farmers' households that are currently poor and vulnerable prefer to use crops that are resistant to drought as their dominant adaptation method. This method does not seem to prevent them from falling below the poverty line in the future. This might have two explanations: (i) these farmers are the so called "typical farmers" who react to persistent climate change by adjusting only their management practices unlike "smart farmers" who adjust their management practices and change their strategies based on accurate information obtained about climate change that allows them feasible adaptation; (ii) they know exactly what to do but they cannot practise the strategies that might help them in the future because these practices are not available or affordable to them.

It should also be noted here that although the farmers have to choose such crops for the purpose of dealing with the negative impacts of climate change, drought-resistant crops are not preferred by many households for consumption[35]. That might be the reason that these farmers' incomes are expected to fall below the poverty line in the future regardless of this effort to adapt to climate change. This may indicate that, although farmers are willing to adapt, most of them have to adjust using strategies that are not favourable to them because they cannot afford to use their preferred strategies. In this case, farmers should be provided with some financial and advisory assistance so that they can use the strategies that are not only appropriate but which they also prefer.

In figures 3.6, 3.7, and 3.8, the climatic shocks and their effects are affected by other household characteristics, that is, gender of the household head, household size, and highest education level attained by any member in the household.

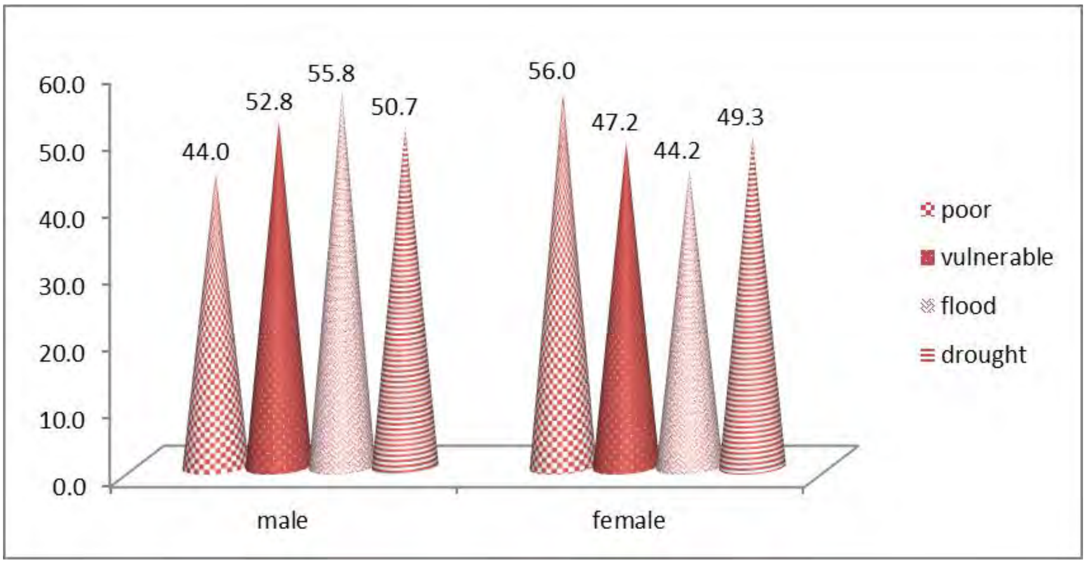
[35] In Tanzania drought resistant crops are millet, sorghum and cassava. These are not preferred by consumers as they taste different from rice and maize which are preferred by more consumers as their staple food.



Source: *Own survey data, December 2010 – January 2011*

Figure 3.6: Poverty, vulnerability and shocks by household size

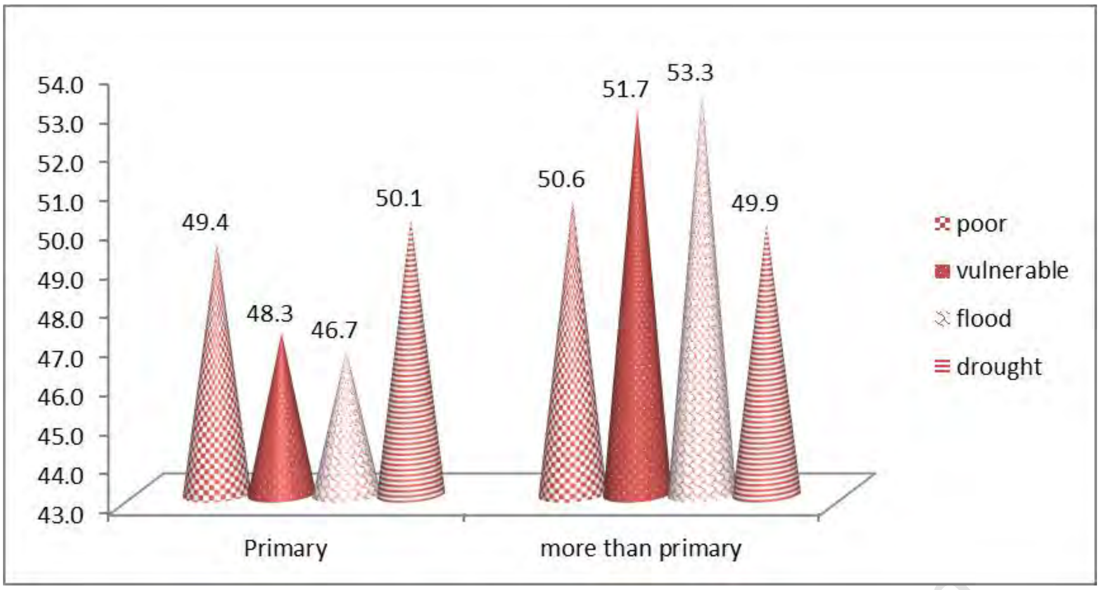
In figure 3.6, for example, among farmers' households that have observed drought in the past 20 years, about 31.7 percent are small households (households with 5 or fewer members). The figures in the same category are about 34 percent for large households (those with more than 10 household members) and for medium households (with between 5 and 10 members). Thirty six point eight (36.8) percent of large households have reported that they experienced floods in the past 20 years while 31 percent of medium households and 32.1 percent of smaller households reported to have experience floods. The results reveal that poverty is severe among large households. Precisely, 78 percent of households that are found to be currently poor are large households while only 0.8 percent of poor households are small households. Likewise, large households are more likely to be poor in the future. The figure shows that almost half of vulnerable households are large households while 20 percent are medium households and only about 10 percent of vulnerable households are small households.



Source: *Own survey data, December 2010 – January 2011*

Figure 3.7: Poverty, vulnerability and shocks by Gender

Figure 3.7 shows that households that are headed by males reported to have experience more climatic shocks than their counterpart female headed households. About 51 percent and 56 percent of male headed households reported to observe drought and floods in the past 20 years, respectively. The results for the effects of shocks are quite interesting. While households with female household heads are currently poorer (56 percent) compared to the 44 percent of male headed households, almost 52 percent of male headed households are expected to be poor in the future while this is true of 47.2 percent of female headed households. These results are not surprising because female are known to be more risk averse than male. It is expected that, even if female headed households are currently poor, they will take measures to cushion themselves from the effects of climate change so that in future they do not fall below the poverty line.



Source: *Own survey data, December 2010 – January 2011*

Figure 3.8: Poverty, vulnerability and shocks by education level in the household

Figure 3.8 shows that, all farmers' households regardless of the education status of the household members, reported to experience drought in the past 20 years. Those household members with relatively high education levels seemed to recall more incidences of floods than those whose highest education level is primary school or less. The figures in the same category also show that households with members with more than primary school education are considered to be currently poor and will continue to remain poor in the future. This could be explained by the fact that many village household farmers have the maximum of primary school education. Moreover those with more than primary school education do not involve themselves much in agricultural activities.

3.4.4 Time horizon

Using the previously mentioned vulnerability thresholds, the study calculates the probability of households being vulnerable in different time horizons (within a three year time span) using the following equation as suggested by Del Ninno, et al. (2006)

$$V^* = 1 - \sqrt[n]{1 - V_n}$$

The purpose of calculating the vulnerability time horizon is to examine, given the vulnerability threshold, whether the probability of the household being vulnerable in the near future increases or decreases when the time period increases. This is important because policy makers can take into consideration when they formulate adaptation policies whether the appropriate policies for reducing vulnerability to climate change are short run or long run.

Table 3.3 below presents the results for the vulnerability threshold for a three year time horizon with a poverty line of TZS. 1592. The study uses 2 vulnerability thresholds. The first, is the typical 0.5 vulnerability threshold. The second is a vulnerability threshold calculated using the chosen poverty threshold of TZS. 1592 divided by Tanzania farmers' income obtained from agricultural output TZS. 3936 (0.41 vulnerability threshold). The results reveal that, with the same poverty line, as the time period increases, the number of vulnerable households decreases at any given vulnerability threshold.

Table 3.3: Vulnerability thresholds a for 1 to 3 year time horizon with a poverty line of TZS. 1592

Time horizon	**Vulnerability Threshold V***	
	0.5	**0.41**
1 year (short term	0.5	0.41
2 years	0.293	0.232
3 years (medium term)	0.206	0.161

Source: *Own calculation using survey data, December 2010 – January 2011*

3.4.5 Model for estimation of vulnerability

After assessing the prospects of farmers in Tanzania being poor in the future due to climate change and identifying the characteristics of farmers who are vulnerable, the study estimates whether their adaptation to climate change affects the prospects of farmers being poor, and then evaluates the adaptation methods that are effective in reducing farmers' vulnerability to climate change for different agro-ecological zones. First, we perform multicollinearity tests to check whether independent variables in the models to be estimated do not provide redundant information about the response variables. We test for the presence of multicollinearity using the Variance Inflation Factor, $VIF_j=1/(1-R^2_j)$ where R^2_j is the coefficient of determination of the model which includes all independent variables except the j^{th} variable. Table 3.4 below shows that the VIF for all variables is less than 10 and hence we can conclude that there is no problem with multicollinearity.

Table 3.4: Test for Multicollinearity

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond. Index	R-Squared
Age of the head of household	1.08	1.04	0.927	2.435	1	0.072
Head of household is male	1.05	1.02	0.9528	1.949	1.117	0.047
Highest education in the household (# of years)	1.38	1.18	0.723	1.496	1.275	0.277
Farm size (in hectares)	1.17	1.08	0.856	1.286	1.376	0.147
Household own livestock	1.12	1.06	0.891	1.204	1.421	0.109
Distance from output markets (in kilometres)	1.56	1.25	0.648	1.169	1.443	0.358
Access to credit	1.1	1.05	0.906	1.011	1.552	0.098
Average rainfall in household's neighbourhood in 2010	4.33	2.08	0.239	0.988	1.569	0.769
Average temperature in household's neighbourhood in 2010	4.37	2.09	0.228	0.941	1.608	0.773
maize is a major crop	1.51	1.23	0.664	0.793	1.752	0.336
rice is a major crop	2.06	1.43	0.486	0.727	1.83	0.515
sorghum is a major crop	2.34	1.53	0.425	0.622	1.978	0.575
Use short crop	1.37	1.17	0.739	0.581	2.045	0.261
Use crops resistance to drought	1.15	1.07	0.879	0.418	2.411	0.129
Use Irrigation	1.23	1.11	0.816	0.261	3.049	0.189
Plants trees	1.35	1.16	0.739	0.112	4.651	0.265

Note:

Mean VIF 1.76 Condition Number 4.6519 Determinant of correlation matrix 0.0312

Table 3.5 below presents the vulnerability assessment results in two Ordinary Least Square (OLS) regressions, followed by two weighted Feasible Generalized Least Square (FGLS) regressions as explained in the model specification section. The estimated coefficients represent elasticities and standard errors are presented in brackets. The results show that signs of the variables in both regressions (OLS and FGLS) are the same, and most of the same variables are significant at 1, 5 and 10 percent significance levels. The F-statistics and their corresponding p-values in all regressions reject strongly the null hypothesis that all the explanatory variables are equal to zero.

The results show that age of household head, farm size, distance from output market, access to credit, average annual rainfall, average annual temperature, and maize and rice as major crops are all statistically significant in the two equations (the OLS and weighted FGLS). The interpretation of the results will base on the weighted feasible generalized least square (weighted FGLS) because it corrects for heteroskedasticity[36].

The coefficient for age (-0.01) indicates that income from agricultural outputs decreases with age. That is, younger farmers' households have more income from agricultural outputs than those of older farmers. Specifically this means that for every year the household head ages, the income from agricultural outputs decreases by 1 percent. This might be because younger people who are determined to work as farmers work harder than older people. There is a statistically significant positive relationship between farm size and income from agricultural outputs. This demonstrates the importance of cultivated land. The results show that a 1 hectare increase in farm size leads to an increase of approximately 20 percent in agricultural outputs.

The effect of distance from output markets is statistically significant, meaning that the further the farmers reside from output markets the higher the farm income. The result shows that a one kilometre increase in the distance of the household from output markets increases farmers' income from agricultural outputs by almost 2 percent. This might appear strange, but in this case the farmers reveal that when the output market is very far from their residence, they opt not to transport their output to the market. Instead, the buyers come to purchase their products from them. Thus transportation costs are not incurred. Farmers are being strategic by preferring to sell their products on the farm. If they had to transport their produce to the market they would have incurred a proportionately larger per unit cost than the buyers due to the different quantities moved by each party. As the buyers' per unit costs are lower they are willing to share part of the transport cost savings with the farmers. Therefore, in the final analysis, farmers end up with a higher income from on-farm sales than from market sales.

[36] The study conducted the Breusch-Pagan / Cook-Weisberg test for heteroskedasticity. The results of the test is $Chi^2(16) = 61.15$ with Prob > $Chi^2 = 0.0000$. The test rejects the Null hypothesis of homoskedasticity. This means at least in one of the independent variables in the regression, the error variances increases as the predicted values of dependent variable increase. Therefore, there is heteroskedasticity problem and the use of FGLS model was important

The coefficients for the dummy variables compare the effect of that variable to the base case. For example 0.01 for maize and rice as major crops implies that the mean level of agricultural outputs for farmers' households who grow maize and rice as their main crops is 1 percent more than it is for those who grow cassava as their major crop. There is a negative relationship between access to credit and income from agricultural outputs. This implies that income from agricultural outputs for farmers' households who have access to credit decreases by 9 percent compared to those who do not have credit access. This can partly be explained by the fact that many farmers do not have this access but those who do tend to use the money they borrowed for activities other than agricultural ones.

There is no doubt that Tanzanian agriculture is very much dependent on rainfall. In this case the more rainfall the better the agricultural outputs. The results show that on average, a one millimetre increase in average rainfall in the household's neighbourhood increases income from agricultural outputs by 0.1 percent. The results further reveal that the impact of average annual temperature is negative and statistically significant. The results suggest that a one degree increase in average annual temperature decreases farm income by 7.4 percent. This is in line with IPCC (1997) who point out that when the crops are at high levels of temperature tolerance, a small increase in temperature will affect the output negatively.

Table 3.5: Regression Results: Factors affecting farmers' income; three-step Feasible Generalized Least Square

	OLS				WEIGHTED FGLS			
	Ln farm income p.c	**Std errors**	**Var (Ln farm income p.c)**	**Std errors**	**Var (Ln farm income p.c)**	**Std errors**	**Ln farm income p.c**	**Std errors**
Age of household head	-0.01***	[0.002]	0.001	[0.002]	-0.0002	[0.002]	-0.01***	[0.002]
Male headed households	0.023	[0.063]	0.024	[0.058]	0.007	[0.053]	0.013	[0.062]
The highest education in the household	0.004	[0.01]	0.01	[0.009]	0.007	[0.009]	0.004	[0.01]
Farm size (in hectares)	0.203***	[0.038]	-0.03	[0.035]	-0.021	[0.032]	0.20***	[0.037]
Household own livestock	-0.003	[0.002]	0.001	[0.002]	0.001	[0.002]	-0.003	[0.002]
Distance from output markets (in kilometres)	0.022**	[0.008]	0.017*	[0.007]	0.015**	[0.007]	0.022**	[0.007]
Access to credit	-0.104*	[0.056]	-0.069	[0.051]	-0.049	[0.048]	-0.09*	[0.054]
Average rainfall in household's neighbourhood in 2010	0.001**	[0.0002]	-0.0001	[0.0003]	-0.00004	[0.0002]	0.001**	[0.0002]
Average temperature in household's neighbourhood in 2010	-0.068**	[0.024]	0.012	[0.022]	0.001	[0.021]	-0.074**	[0.023]
maize is a major crop	0.01**	[0.002]	-0.002	[0.002]	-0.002	[0.002]	0.01**	[0.002]
rice is a major crop	0.014***	[0.003]	-0.002	[0.003]	-0.001	[0.002]	0.013***	[0.003]
sorghum is a major crop	0.01	[0.002]	0.004	[0.002]	0.004	[0.002]	0.001	[0.002]
Use short crop	0.019	[0.065]	0.094	[0.06]	0.099	[0.056]	0.024	[0.064]
Use crops resistance to drought	0.104	[0.123]	-0.067	[0.114]	-0.092	[0.091]	0.09	[0.111]
Use Irrigation	-0.001	[0.112]	0.078	[0.103]	0.088	[0.096]	-0.017	[0.111]
Plant trees	-0.058	[0.081]	0.049	[0.075]	0.024	[0.069]	-0.06	[0.079]
Constant	8.633***	[0.452]	0.048	[0.417]	0.27	[0.389]	8.763***	[0.444]
Observations	**556**		**556**		**556**		**556**	
F- statistic (P-value)	**10.17 (0.0000)**						**9.93 (0.0000)**	
R-squared	**0.23**		**0.04**		**0.04**		**0.23**	

Note: *Dependent variable is natural log of per capita income derived from farm output*
*Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.*

3.4.6 Binary Logit Model: Farmers' probability of income falling below the poverty line now and in the future

This study also ran the binary logit model so as to find out what determines the probability of farmers' households being currently poor or their income falling below the poverty line in the future. The dependent variables (vulnerability and poverty) are the dummy variables whereby the household is given the vulnerability value of 1 if it has a vulnerability value of more than 0.5, and 0 otherwise. For the poverty variable, the household is given the value of 1 if it currently has a per capita farm income of less than USD 1, and 0 otherwise. Table 3.7 (see Appendix 3.1 below) presents the results of marginal effects from the logit model estimating the characteristics of a typical farmers' likelihood of income falling below the poverty line[37]. The log-likelihood ratio test strongly rejects the null hypothesis that all the coefficients in the regression equation take the value of zero. We therefore conclude that the variables included in all the models explain the variation in the regressand. The logit model parameters are estimable up to a scaling factor. The coefficients of the logit model give the change in the mean of the probability distribution of the dependent variable associated with the change in one of the explanatory variables, but these effects are usually not of primary interest. The marginal effects on the probability of possessing the characteristic can be of more use. The marginal effects vary across households and in this case, they indicate by how much the probability of a farmers' income falling below the poverty line changes with changes in the explanatory variables.

Being poor

The results of the logit model shown in table 3.7 (see Appendix 3.1 below), show that the probability of the income of a typical Tanzanian farmer currently falling below the poverty line decreases with the age of household head; household size; farm size; residing in alluvial and semi-arid agro-ecological zones; the fact that the household has non-farm income; and using irrigation as a dominant adaptation method. The probability increases with the average temperature in the household's neighbourhood; residing in coastal agro-ecological zone; and using short season crops and crops that are resistant to drought as dominant adaptation methods.

[37] The results for binary logit model are presented in table 3.7 (see Appendix 3.1 below).

The results from the marginal effects in table 3.6 reveal that as household heads age, the probability of that household being poor decreases. This can possibly be explained by the fact that older household residents might be more experienced in agriculture and their awareness of climate in their area is more extensive. In analysing the relationship between poverty status and farmers' household size, it is possible to come up with either of the two opposing explanations. The first one is that as household size increases, the total household consumption increases as well leading to greater household poverty. The second (opposing) explanation is that, when the size of a farmers' household is large, there is the potential for more members to supply labour and thus poverty can be minimised with the income generated. The results from table 3.6 reveal that the marginal effect of small households (with five or fewer household members) and medium sized households (with household members of between 6 and 10 people) are -0.477 and -0.059 respectively. This indicates that small and medium sized households are 47.7 percent and 5.9 percent less likely to be poor compared to the base case (household size of more than 10 members). A positive relationship between household size and poverty status was also found in Ogwumike and Akinnibosun (2013) and Schubert (1994).

With respect to farm size, farmers with more hectares are less likely to be poor than farmers with less farmland. On average, owning one more hectares of land decreases the probability of the household being poor by 2.5 percent. In Tanzania, farm plots are the physical assets of the farmers' households. They can be used as collateral if the farmer is in need of a loan from a financial institution. By so doing, they can improve their standard of living. Similarly, the farmers with more land can increase their income by having more output if the farms are well managed. A similar finding was obtained by Olaniyan (2000) showing that there is a negative relationship between house ownership and poverty status within farming households.

The marginal effects reveal that farmers' households in the alluvial and semi-arid agro-ecological zones have a 3 and 1.4 percent respectively lower probability of being poor compared to farmers who reside in the arid agro-ecological zone. The arid zone is characterised by poor rainfall which makes agriculture difficult, and farmers in this area are thus disadvantaged compared to farmers in other areas. In line with this, the results reveal that a centigrade degree increase in temperature above the average increases the probability of a household being poor by 0.9 percent. Crops have a temperature range that is suitable for their growth and an increase in temperature above the tolerance level decreases the agricultural output and will affect farm income. Farmers using irrigation as their dominant adaptation method have almost 1 percent probability of reducing their poverty than those who are not adapting. Although irrigation is considered to be one of the most expensive adaptation methods and not easily available, the study reveals that farmers who use irrigation to deal with the negative impact of climate change are less likely to be poor.

These marginal effects further indicate that farmers who have non-farm income are 1.2 percent less likely to be poor than their peers who do not have non-farm income. The study acquired household information concerning all non-farm income generating activities per year. It was assumed that the farmers' households with non-farm income are likely to cover their consumption needs even when the climatic condition is not suitable for agricultural activities. In this case, farmers' households with these incomes are not likely to fall below the poverty line.

Being vulnerable

The results for "vulnerability" status shown in table 3.6 reveal that the probability of the farmers' household being vulnerable increases with the highest education attained by any member in the household, farm size, distance from output market, average temperature in the neighbourhood, and incidence of flood in the past 20 years. The likelihood of future poverty decreases with the age of the household head, household size, access to credit, growing maize and sorghum as major crops, and using short season crops as a dominant adaptation method.

The marginal effects results reveal that an increase of one year in the age of the household head decreases the probability of households being poor in the future by 1 percent. The results imply that households that are headed by younger people are expected to be poor in the future regardless of their initial condition. This might be because most young household heads have more household responsibilities than older household heads. Young household heads are expected to have dependent children, take care of old parents, and carry out many more household tasks. In this case, saving is difficult and if it happens that in the future there are also unfavourable weather conditions for agriculture, then the income of the household can easily fall below the poverty line.

An increase in household size increases the probability of the household's income falling below the poverty line in the future. The results also reveal that the marginal effects of small and medium sized households are -0.887 and -0.457 respectively. Small and medium-sized households are 88.7 percent and 45.7 percent less likely to be poor in the future compared to the base case.

An increase of 1 hectare in farm size leads to an 11.3 percent increase in the probability of the household being poor in the future. This might be because taking care of a big plot impoverishes smallholder farmers in this era of rainfall-shortages, taking into consideration that many farmers depend on rain-fed agriculture. Farmers that have more than primary school education are 2 percent more likely to fall below the poverty line in the future than those with only primary school education or less. This could be explained by the fact that many village smallholder farmers only have maximum of primary school education. Moreover, the household heads with more than primary school education do not involve themselves much in agricultural activities.

An additional kilometre in distance from output market increases the probability of the household's being vulnerable to climate change by 4 percent. It is important to note the significance of distance to output markets for farmers' households' vulnerability. Many of the farmers find it too costly to transport their agricultural harvests to the market. The increase in distance from output market increases the cost of transporting the crops to the market. Thus the output price received for products has these transport costs deducted which leads to a decrease in farmers' income and therefore an increase in their vulnerability. This might explain the reason why farmers tend to sell their products at the farm areas. Farmers who have access to credit are 18.6 percent less likely to become poor in the future compared to their peers who do not have access to credit. Access to credit is very important for farmers' households because they can use the credit to finance their households' consumption in case the agricultural yields are not adequate. The marginal effect results show that farmers who own livestock are 1 percent less likely to fall below the poverty line in the future compared to farmers without livestock. Apparently, livestock acts as a measure of wealth in farmers' households. The households that own livestock use their livestock to smooth their consumption in the case of climatic shocks. This ties in with results for famers with non-farm income. The results reveal that farmers with non-farm income are 16.3 less likely to fall into poverty in the future. These households can use their non-farm income to smooth their consumption if farm income erratic.

Vulnerability to climate change

The vulnerability of the farmers' status depends on a combination of factors, including climate variables. The marginal effect results confirm this. Specifically the results reveal that 1 millimetre increase in rainfall reduces the future probability of the farmers' household income falling below the poverty line by 0.1 percent. As so many Tanzanian smallholder farmers rely on rainfall for their agricultural activities, the probability of them being vulnerable significantly and positively correlates with average temperature. The likelihood of farmers being vulnerable is higher in regions with higher temperatures. The marginal effect results show that a 1 degree centigrade increase in average annual temperature increases the likelihood of farmers' income falling below the poverty line by 4.5 percent. Thus if the measures to reduce the impact of changes in temperature are not taken, it is expected that higher temperatures will generally have a more negative effect on the future welfare of farmers'.

The results for the dummy variable for experience of floods reveal that farmers who have experienced flood in the past 20 years are 11.5 percent more likely to be vulnerable than their counterparts. In the presence of flood, agricultural activities become difficult. Flood tends to destroy the crops as well as the farmers' other property. As has been shown, livestock ownership reduces the probability of farmers being poor in the future, and floods would destroy livestock and make their future poverty more likely.

The agro-ecological zones in which farmers reside also have an impact on their vulnerability. The Arid agro-ecological zone is characterized by a disadvantageous climate for rain-fed agriculture. In Tanzania, the arid zone is characterised by volcanic ash and sediments and rolling plains with relatively infertile soil. This zone also has a unimodal and unreliable rainfall pattern of around 400 to 600mm (URT, 2007). All those characteristics make this zone unsuitable for rain-fed agriculture. The marginal effects are that farmers that reside in the alluvial and semi-arid agro-ecological zones are better off. They are respectively 24.5 and 40.9 less likely to be vulnerable compared to their peers in the arid zone.

It is clear that one cannot halt climate change, but it is possible to reduce the resulting impact. This depends on how the farmer is prepared to adapt. The statistical analysis in this study confirms that farmers with effective strategies for adapting to climate change become less vulnerable. While the results reveal that the use of irrigation is important in reducing the probability of the farmers' household becoming poor, the use of short season crops seems to be the only adaptation method that significantly reduces vulnerability. The study shows that the household that chooses to use short season crops as its dominant adaptation method has a 12.1 percent lower probability of being vulnerable compared to the household that does not adapt at all. In Tanzania farmers are introduced to alternative seeds for different crops especially maize that can be ready for harvest in a short period compared to traditional seeds.

This option was introduced by the government due to the variability of the rainfall in the country. Currently the rainy seasons and the amount of rainfall are shorter than in the past. In this case, if the farmer plants traditional seeds, the probability that the rainy season will come to an end before the crops are ready is high. Agricultural yields will decrease with a resultant decrease in income for households.

Table 3.6: Marginal Effects: The determinants of farmers' incomes falling below the poverty line

VARIABLES	Vulnerability		Poor	
	dy/dx	**Std Errors**	**dy/dx**	**Std Errors**
Socio-economic factors				
Age of household head	-0.01**	[0.002]	-0.0004*	[0.0002]
Small households #	-0.887***	[0.032]	-0.477***	[0.08]
Medium sized households #	-0.457***	[0.101]	-0.059**	[0.026]
Male headed households #	0.063	[0.066]	-0.009	[0.009]
More than primary school education #	0.02*	[0.012]	0.001	[0.001]
Farm size	0.113***	[0.042]	-0.025**	[0.011]
Household owns livestock #	-0.01**	[0.003]	0.0001	[0.0001]
Use short season crop #	-0.121*	[0.069]	0.014	[0.009]
Use crops resistance to drought #	-0.07	[0.097]	0.019	[0.013]
Use Irrigation #	0.026	[0.134]	-0.01*	[0.005]
Plants trees #	-0.101	[0.129]	0.003	[0.006]
Economic factors				
Have non-farm income #	-0.163**	[0.067]	-0.012**	[0.006]
Distance from output markets	0.04***	[0.009]	-0.0002	[0.001]
Access to credit #	-0.186**	[0.065]	-0.003	[0.005]

VARIABLES	Vulnerability		Poor	
Environment/climate factors				
Average rainfall in household's neighbourhood in 2010	-0.001*	[0.0003]	-0.00002	[0.00003]
Average temperature in household's neighbourhood in 2010	0.045**	[0.023]	0.009*	[0.005]
Experienced drought in the past 20 years	0.022	[0.084]	0.004	[0.006]
Experienced flood in the past 20 years	0.115*	[0.067]	0.002	[0.007]
Reside in Coastal#	-0.169	[0.219]	0.123	[0.136]
Reside in Plateau #	-0.164	[0.166]	-0.01	[0.006]
Reside in Alluvial #	-0.245**	[0.12]	-0.031**	[0.014]
Reside in Southern highland #	-0.185	[0.161]	-0.008	[0.006]
Reside in Semi-arid #	-0.409***	[0.105]	-0.014**	[0.007]
Observations	**556**		**556**	
Marginal effect after logit	**0.57946583**		**0. 01135277**	

Note:

- *Dependent variables are the probability that the farmer is vulnerable, and the farmers' household is currently poor,*
- *Base category for dominant adaptation is no adaptation*
- *Base category for household size is large households (the household size is more than 10 members)*
- *Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

3.5 Conclusion and recommendations

The aims of this study were fourfold: (i) to assess the prospects of farmers in Tanzania being poor in the future due to climate change, (ii) to identify the characteristics of farmers who are vulnerable to climate change, (iii) to estimate whether adaptation to climate change affects the prospects of farmers being poor, and (iv) to evaluate the adaptation methods that are effective in reducing farmers' vulnerability to climate change for different agro-ecological zones. The study analysed data from 556 randomly selected households from Morogoro, Tanga, Iringa and Dodoma administrative regions representing six of seven agro-ecological regions of the country.

The mean vulnerability index calculated using the three step feasible generalised least square is 0.5252. This means that, on average, within the surveyed Tanzanian households, each farmer faces a 52.5 percent likelihood of experiencing future poverty. The vulnerability to poverty (headcount) ratio is 2.9, which shows that for every poor household there are an additional 3 vulnerable households that need to be targeted by policy actions so that they may avoid future poverty. The statistics show that many households in the Semi-arid zone are vulnerable with a ratio of 26. This study recommends that policy interventions promote effective adaptation strategies for farmers' households residing in the Semi-arid zone[38]. Although large households are more vulnerable, the statistics reveal that the concentration of vulnerable households is among small households, that is, the vulnerability to poverty ratio among small households is higher than among large households. Taking into consideration that almost 50 percent of the surveyed farmers' households are small households (have 5 and fewer household members), the Tanzanian government should assist these farmers to reduce their vulnerability to climate change. By reducing the susceptibility of this large population, the government may alleviate a large part of the problem caused by climate change.

Comparing two vulnerability thresholds (0.5 and 0.41), over a three years period, the vulnerability situation improves in the long run. The results reveal that, fewer farmers' households are likely to become poor as the number of years increases. In this case, therefore, policy makers should target long term policies so that vulnerability to climate change can be eliminated.

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[38] The relevance of the following chapter is that it looks at the adaptation methods that are suitable for different agro-ecological zones. After analysing this, the study makes recommendation to policy makers on which adaptation methods are relevant to a specific agro-ecological zone.

In examining the characteristics of the farmers' households which are most susceptible to future poverty, the study found that households with the following characteristics are more vulnerable to climate change: those with large farms, those that reside far from output markets, those that reside in a neighborhood where temperatures are high, those that reported to have experience flood in the past 20 years and households with heads that have more than primary school education. When designing a policy that will reduce farmers' vulnerability to climate change, we recommend that the government should formulate policies that target these households.

The weighted FGLS results from the three-step feasible generalised least square model reveal that farm size, distance from output market, average annual rainfall, and growing maize and rice as major crops tend to increase income derived from the farm. It is expected that the farmers' households will be able to increase their income if the mentioned variables are optimal.

Using a binary logit model, the study found that there are some adaptation methods that are vital in reducing current and future household poverty. Farmers' households that use irrigation as their dominant adaptation method have 1 percent lower probability of falling below the poverty line while farmers' households that use short season crops have a 12.1 percent lower likelihood compared to the base case. Thus, the results in this study confirm that farmers need to recognize changes in the climate and respond by undertaking adaptation measures. However the choice of adaptation method also matters in reducing the negative impacts of climate change. Therefore, the major role that the Tanzanian government needs to play regarding the effects of climate change on smallholder agriculture, is to help farmers overcome constraints they face in taking up appropriate adaptation methods. For example, there is a need for the government to develop irrigation infrastructure especially in the arid agro-ecological zone to help farmers in their agricultural activities in order to reduce their risk.

The results reveal that changes in climate variables like rainfall, temperature, and incidence of flood significantly impact farmers' current and future poverty. Farmers who experience floods are more likely to be vulnerable than those who do not live in flood-prone areas. With regard to natural disasters, the government of Tanzania needs to encourage farms to insure against these disasters as this could compensate farmers for their losses. The government should also provide education on the type of crops suitable for the amount of rainfall and temperature in farmers' agricultural areas.

The results from the binary logit model further show that the following are important factors in the reduction of current and future poverty as a result of climate change: The age of the household head, household size, the fact that the household is headed by male, farm size, distance from output market, access to credit, growing maize and sorghum as major crops, and the fact that the household has non-farm income. In this case, policy intervention that promotes access to credit for farmers is useful in helping farmers reduce the probability of future poverty. It is also recommended that the Tanzanian government invest in rural infrastructure to improve access to markets, which can improve farmers' livelihoods and lessen their vulnerability.

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Appendix 3.1:The determinants of farmers' incomes falling below the poverty line.

Table 3.7: Logit model: The determinants of farmers' incomes falling below the poverty line.

VARIABLES	**Vulnerability**		**Poor**	
	Coeff.	**Std Errors**	**Coeff.**	**Std Errors**
Socio-economic factors				
Age of household head	-0.02**	[0.01]	-0.038**	[0.017]
Small households #	-5.714***	[0.605]	-8.811***	[0.924]
Medium sized households #	-1.977***	[0.509]	-4.668***	[0.601]
Male headed households #	0.254	[0.265]	-0.712	[0.473]
More than primary school education #	0.084*	[0.048]	0.047	[0.077]
Farm size	0.463***	[0.172]	-2.247***	[0.345]
Household owns livestock #	-0.023**	[0.011]	0.008	[0.011]
Use short seasons crop #	-0.492*	[0.279]	1.033**	[0.467]
Use crops resistance to drought #	-0.284	[0.393]	1.129**	[0.531]
Use Irrigation #	0.107	[0.559]	-1.577	[1.2]
Plant trees #	-0.407	[0.517]	-0.299	[1.144]
Economic factors				
Have non-farm income #	-0.665**	[0.276]	-1.27**	[0.508]
Distance from output markets	0.169***	[0.038]	-0.022	[0.075]
Access to credit #	-0.772**	[0.273]	-0.303	[0.457]
Environment/climate factors				
Average rainfall in household's neighbourhood in 2010	-0.002*	[0.001]	-0.002	[0.002]
Average temperature in household's neighbourhood in 2010	0.184**	[0.096]	0.781***	[0.225]
Experienced drought in the past 20 years	0.092	[0.342]	0.406	[0.732]
Experienced flood in the past 20 years	0.484*	[0.288]	0.171	[0.577]
Reside in Coastal#	-0.689	[0.898]	3.479**	[1.609]
Reside in Plateau #	-0.663	[0.681]	-1.438	[1.179]

VARIABLES	Vulnerability		Poor	
Reside in Alluvial #	-1.003**	[0.509]	-3.991***	[0.787]
Reside in Southern highland #	-0.748	[0.668]	-1.206	[1.097]
Reside in Semi-arid #	-1.807***	[0.592]	-3.007**	[1.368]
Constant	6.633**	[2.598]	25.437***	[5.844]
Observations	**556**		**556**	
Log likelihood	**-219.52437**		**-92.516472**	
Wald $\chi 2$ (p-value)	**176.72 (0.0000)**		**132.92 (0.0000)**	

Note:

- *Dependent variables are the probability that the farmer is vulnerable, and the farmers' household is currently poor.*
- *Base category for dominant adaptation is no adaptation*
- *Base category for major crops is cassava*
- *Base category for household size is large households (the household size is more than 10 members)*
- *Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% significance levels respectively.*

Appendix 3.2: Survey Questionnaire on Adaptation by Smallholder Farmers in Tanzania to Climate Change.

Introduction

Good morning/ Afternoon

My name is Coretha Komba. I am a PhD student at the School of Economics at the University of Cape Town (UCT), South Africa. I am conducting a household survey on Adaptation methods to climate change. I would like to find out your views about the current discussion on climate change and also I would want to know what factors influence your choice of adaptation methods. Your household has been randomly selected in this important study. Your participation will be highly appreciated. All answers you provide will be handled confidentially and will be used solely for research purposes.

I: Socio-economic variables

1. Farmers' information:

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

   Education level of the head of the household……………………………

   Highest education level of any other member of the household…………….

   Gender of the head of the household…………………………………

   Marital status of the head of household………………………………..

   Number of years working as a farmer…………………………………

   Size of the household…………………………………………………..

   Size of your farm land…………………………………………………..

   Number of livestock ………………………………………………….

   Village of the household………………….……………………………..

   District of the household………………………………………………

   Region of the household………………………………………………

   Date of the interview…………………………………………………..

2. On average, how many bags of crops do you harvest and use for food per year? For what price do you normally sell a bag of your crops? Please indicate in a table below

Type of crop	**Hectares**	**Harvest**	**Use for food**	**Price per bag of crop (TZS)**
Maize				
Rice				

Beans				
Sorghum				
Sweet potatoes				
Potatoes				
Cassava				
Vegetables				
Onions				
Others (Specify) (i) (ii) (iii) (iv)				

3. Apart from agriculture, do you have any other means of earning income?

   ☐ Yes

   ☐ No

4. If yes, what are those other means and on average how much do you earn from those other means per year?

Other means	**Average amount (in TZS)**				
	<100000	110,000- 300,000	310,000- 500,000	510,000- 1,000,000	>1,010,000

5. If no, which other means would you want to have and on average how much would you expect to earn from those other means per year?

Other means	**Average amount (in TZS)**				
	<100000	110,000- 300,000	310,000- 500,000	510,000- 1,000,000	>1,010,000

6. To which information systems do you have access? Please tick all which apply.
   - TV
   - Radio
   - Newspapers
7. Do you own any communication device (telephone, cell phone, etc)?

   ☐ Yes

   ☐ No
8. How many times have you received food aid in the past 2 decades? Please tick.
   (i) Never
   (ii) 1 – 5 years
   (iii) 6 – 10 years
   (iv) 11 – 15 years
   (v) 16 – 20 years
   (vi) Every year
9. Why did you receive food aid? Please explain

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

   …………………………………………………………………………………………………

   ………………………………

II: Climate change and Adaptation methods variables

10. Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in the rainfall patterns? ☐ Yes

    ☐ No
11. If yes, has the mean and/or variance increased or decreased?

    Mean : Increased/Decreased …………..

    Variance : Increased/Decreased …………...
12. Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in temperature? ☐ Yes

    ☐ No
13. If yes, has the mean and/or variance increased or decreased? ……………………………

    Mean : Increased/Decreased …………..

    Variance : Increased/Decreased …………...

14. Have you observed drought (as a result of increase in temperature) in the past 2 decades?

☐ Yes

☐ No

15. On average, how many times/years have you observed drought in the past 2 decades?
16. Have you observed floods (as a result of increase in precipitation) in the past 2 decades?

☐ Yes

☐ No

17. On average, how many times/years have you observed floods in the past 2 decades?
18. What actions (and in what proportion) have you been taking in your agricultural activities to respond to the precipitation variability observed? Please list below

Plot area	Crop	Hectares	Action	Planned	Implemented	Proportion	Constraints

19. What actions (and in what proportion) have you been taking in your agricultural activities to respond to the temperature variability observed? Please list below

Plot area	Crop	Hectares	Action	Planned	Implemented	Proportion	Constraints

20. What other actions might you have had in mind but did not take and why? Please list below

Plot area	Crop	Action	Reasons for not taking

III: Economic and Institutions variables

21. How far away is the market where you buy your agricultural inputs is (e.g. hoes, seeds, fertilizers, etc)? Please tick

(i) Less than 1 km

(ii) 1 to 5 km

(iii)6 to 10 km

(iv)Over 10 km

22. How far the market where you sell your agricultural outputs is? Please tick

(i) Less than 1 km

(ii) 1 to 5 km

(iii)6 to 10 km

(iv)Over 10 km

23. Are you a member of any community group (e.g. SACCOS)?

☐ Yes

☐ No

24. If yes, please mention the name(s) of the group(s) of which you are a member

(i) ………………………………………………….

(ii) …………………………………………………

(iii)………………………………………………….

(iv)………………………………………………….

25. If no, which group(s) would you want to join?

(i) ………………………………………………….

(ii) ……………………………………………………….

(iii)…………………………………………………….

(iv)………………………………………………….

26. What kind of support do you get from your group? Please mention

(i) ………………………………………………

(ii) ……………………………………………..

(iii)………………………………………………

(iv)………………………………………………

27. Is some of the support agricultural extension? ☐ Yes

☐ No

28. Do you have access to any formal credit (from banks, SACCOS etc)?

☐ Yes

☐ No

29. Do you have access to any informal credit (from neighbours, friends, relatives etc)?

☐ Yes

☐ No

30. Does the Government have any rule/ regulation of which you are aware which supports adaptation to climate change? ☐ Yes

☐ No

31. Do you receive any agricultural technical support from the Government in implementing adaptation? ☐ Yes

☐ No

32. If yes, what kind of technical support do you receive? Please mention.

(i) ……………………………………………………….

(ii) ………………………………………………………

(iii)………………………………………………………

(iv)………………………………………………………

(v) ………………………………………………………

33. If no, what kind of support would you want to receive? Please mention.

(i)……………………………………………

(ii)…………………………………………….

(iii)………………………………………………………

(iv)……………………………………………………….

What in your opinion is the best way to implement adaptation in your area? Please explain your answer.

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

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Chapter 4: Adaptation to Climate Change by Smallholder Farmers in Tanzania

Abstract

In Sub-Saharan Africa, climate change is set to hit the agricultural sector the most severely and cause suffering particularly for smallholder farmers. To cushion themselves against potential welfare losses, smallholder farmers need to recognize the changes already taking place in their climate and undertake appropriate investments in adaptation. This study investigates whether these smallholder farmers in Tanzania recognize climate change and, consequently, adapt to it in their agricultural activities. The study also investigates the factors influencing their choice of adaptation methods. In order to achieve this, the study analysed data from 534 randomly selected households in a sample of districts representing the six of the seven agro-ecological regions of the country. The data shows that Tanzanian smallholder farmers have observed changes in mean and variance precipitation and temperature and responded to it. The farmers have generally used short-season crops, drought-resistant crops, irrigation, changing planting dates and tree planting to adapt to the negative impacts of climate change on their agricultural yields. In this study, selection bias is corrected using a Heckman sample selection model. A binary probit model is used as a selection equation to investigate the factors influencing a farmer's decision to undertake any adaptation at all to climate change while a multinomial probit model is used as an outcome equation to investigate the factors influencing farmers' choice of specific adaptation methods. The inverse Mill's ratio reported selection bias in choosing three of the adaptation methods. The findings of the study suggest that the Tanzanian government needs to assist smallholder farmers overcome the constraints they face in their attempts to adapt. The government can play a significant role by promoting adaptation methods appropriate for particular circumstances e.g. particular crops for different agro-ecological zones.

Key words: *Adaptation methods, smallholder farmers, agro-ecological zones, climate change*

4.1 Introduction

Agriculture is the most important sector in Sub-Saharan Africa (SSA) and is set to be hit the hardest by climate change. Indeed, this is confirmed by several studies. (see for example, Deressa, 2006; Moussa et al., 2006; Jain, 2006; Hassan et al., 2008; Molua et al., 2006. & Mano et al., 2006). Although climate change may affect the agricultural sectors of different countries in different ways, what is clear is that these changes will bring about substantial welfare losses especially for smallholders whose main source of livelihood derives from agriculture. There is a need for nations to neutralize the potential adverse effects if welfare losses to this vulnerable segment of the society are to be avoided. Adaptation seems to be the most efficient and friendly way for farmers to reduce these negative impacts. (Füssel et al., 2006). This can be achieved through the smallholder farmers themselves taking adaptive actions or by governments implementing policies aimed at promoting appropriate and effective adaptation measures.

In order to implement appropriate interventions, governments need to understand the opportunities (or lack thereof) for adaptation and the key drivers behind voluntary adaptation by vulnerable smallholder farmers. Some studies report that agricultural measures such as the use of improved crop varieties, the planting of trees, soil conservation, changing planting dates, and irrigation are the most used adaptation strategies in African countries. Other studies have pointed out several socio-economic, environmental and institutional factors as well as the economic structure, as key drivers influencing farmers to choose specific methods in Africa as a whole and in some specific SSA countries (Deressa et al., 2009; Kabubo-Mariara, 2008; Mideksa, 2009; & Bryan et al., 2009). Thus, there is a need for each nation to understand the scope and the drivers of adaptation to climate change particularly amongst its smallholder farmers in order to craft appropriate policy responses as the vulnerability and sensitivity of each country differs as does the accessibility of the different adaptation methods.

Tanzania is one of the SSA countries in which agriculture is the backbone of the economy. Thus, agriculture remains the largest sector in the economy and hence its performance has a significant effect on output and corresponding income and poverty levels (United Republic of Tanzania, 2003). Tanzanian agriculture is the major source of food, and accounts for about 45 percent of GDP, 60 percent of merchandise exports, 75 percent of rural household incomes and 80 percent of the population's source of employment (Andersson et al., 2005).

Furthermore, agriculture stimulates economic growth indirectly through larger consumption linkages with the rest of the economy than other sectors. Higher and sustained agricultural growth is needed to meet Tanzania's National Strategy for Growth and Reduction of Poverty (NSGRP, also called MKUKUTA in Kiswahili) and Millennium Development Goals of halving poverty and food insecurity by 2015 (United Republic of Tanzania, 2005).

Key constraints to achieving Tanzania's agricultural growth targets include: (i) High transaction costs due to the poor state or lack of infrastructure; (ii) Under-investment in productivity enhancing technologies; (iii) Limited access to technology demand and delivery channels – with 60-75 percent of households estimated to have no contact with research and extension services; (iv) Limited access to financing for the uptake of technologies; (v) Un-managed risks with significant exposure to variability in weather patterns with periodic droughts. The impact of these events is amplified by the dependency on rain-fed agriculture and the limited capacity to manage land and water resources; (vi) Weak co-ordination and capacity in policy, and the formulation and implementation of public intervention among the various actors in the sector (United Republic of Tanzania, 2003). Recently, the Tanzanian government adopted the Agricultural Sector Development Strategy (ASDS) and its operational programme (ASDP). The intention of this strategy is to achieve a sustained agricultural growth of about 5 percent annually primarily through transformation from subsistence to commercial agriculture. However, the agricultural development strategy needs to also address the serious challenges posed by climate change, which can become a crucial limiting factor for agricultural growth in the medium to long term. To date, insufficient attention has been paid to the issue of climate change in relation to agriculture. Accordingly, this study will attempt to gather evidence which can form the basis for mainstreaming climate change in discussions surrounding the agricultural sector.

It is important to know whether farmers respond to their perceptions of events. If they do, and they recognize that climate change is occurring, then the state would simply need to assist them overcome constraints they face in implementing appropriate adaptation methods. On the other hand, if they do respond to their perceptions about events but do not recognise change, then the state would need to ensure increased awareness. However, if farmers do not respond at all to their perceptions then the state would need to be proactively involved in ensuring that farmers undertake appropriate adaptation if the impending welfare losses to this vulnerable group in society are to be abated.

The main purpose of this chapter is threefold: (i) to investigate whether smallholder farmers in Tanzania perceive climate change, (ii) to investigate whether, as a consequence, they adapt at all in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods. This study collected data from 556 randomly selected smallholder farming households from four representative administrative regions representing six of the seven agro-ecological regions of the country. The rest of the chapter is arranged as follows: After this introductory section, section 4.2 reviews relevant previous studies on adaptation to climate change by individual farmers. Section 4.3 discusses the methods, variables and data used in this study. Section 4.4 presents and discusses the results. Section 4.5 draws policy implications and concludes the chapter.

4.2 Individual farmers' adaptation to climate change

Research has been undertaken by scholars around understanding farmers' awareness of climate change, options for adaptation to these changes and the factors influencing choice of adaptation methods. Mixed evidence has been presented as to whether farmers are aware that the climate is changing in their areas. For example, Ishaya and Abaje (2008) report a lack of awareness and knowledge by farmers in Jema'a, Nigeria. On the other hand, working on the Nile Basin of Ethiopia, Deressa et al. (2009) report that 50.6% of the surveyed farmers had observed increasing temperatures over the past 20 years whereas 53% of them had observed decreasing rainfall over the past 20 years. Thus, in line with the current definition of climate change, the majority of the surveyed Ethiopian farmers demonstrated awareness. According to Deressa et al. (2009), it appears that the easiest way of assessing this awareness is to inquire from a sample whether they have observed a change in the climate across two adjacent decades (e.g. between the 1990s and the 2000s both in terms of the means and the variances of precipitation and temperature). In that respect, our study will use that approach in its investigation.

It might be expected that farmers who recognize climate change will take some actions to cushion themselves against its adverse effects. In the Ethiopian study, 58% of farmers who claimed to have observed changes in climate over the past 20 years had responded to it by undertaking some adaptation measure. In fact, several studies report agricultural adaptation measures such as the use of crop varieties, planting trees, soil conservation, changing planting dates, diverging from crops production to livestock keeping, and irrigation as the most used adaptation methods in African countries (Deressa et al., 2009; Kabubo-Mariara, 2008;

Mideksa, 2009; Ajao & Ogunniyi, 2011; Bryan et al., 2009). However, it is clear that for various reasons, not all farmers will adapt. In this thesis, the reasons for failing to adapt mentioned by farmers included lack of funds, shortage of water, poor planning, and shortage of seeds.

Several factors have been put forward to explain the presence or absence of adaptation to climate change. Downing et al. (1997) explore fairly standard variables[39] to explain adaptation in Africa. Nhemachena and Hassan (2007) identify the important determinants of adaptation in South Africa, Zambia and Zimbabwe to be access to credit and extension, and also awareness. Their study suggests enhancing access to credit and information about climate and agronomy so as to boost adaptation. Ishaya and Abaje (2008) find that lack of awareness and knowledge about climate change and adaptation strategies, lack of capital and improved seeds, and lack of water for irrigation played an important role in hindering adaptation in Jema'a, Nigeria.

Gbetibouo (2009) proposes that the major driver influencing farmers' adaptation in Limpopo basin, South Africa, is the way that they formulate their expectations of future climate in dealing with the changing weather patterns. According to that study, the major factor restraining farmers' adaptation is inadequate access to credit. The study argues as well that, among other things, the main factors that promote adaptive capacity are farmers' income, the size of the household, farmers' experience, and engaging in non-farm activities. Below, et al. (2012) acknowledge the role of public investment in rural infrastructure, a good education system that allows females equal education opportunities, availability of microcredit services, availability and technically efficient use of agricultural inputs, and availability of agricultural extension in improving the adaptation in Mlali and Gairo.

While analysing farmers' perception of climate change, governance and adaptation constraints in the Niger Delta region of Nigeria, Nzeadibe et al. (2011) also point out that the factors responsible for hindering adaptation are inadequate information, limited awareness and knowledge about adaptation methods, and poor government attention to the phenomenon of climate change. Deressa et al. (2011) also find that education level and gender of the head of the household, size of the household, livestock ownership, availability of credit, and environmental temperature significantly influence the presence of farmers' adaptation.

[39] They mention adaptive strategies in line with generic types of adaptation namely; anticipator; institutional and regulatory; research and technology; and development assistance for capacity building.

Ogalleh et al. (2012) in analysing perceptions and responses in Kenya, find that smallholders' perceptions are that climatic variability is increasing. In dealing with the negative impacts of this variability, the smallholders in this community use diversification of crop varieties, migration and sale of livestock. In addition, West et al. (2008) analysed the local perceptions and regional climate trends on the central plateau of Burkina Faso and found that rural households in the study area vary their agricultural practices, for example, integrating different crop varieties in their agricultural activities and implementing a host of soil and water conservation practices in order to respond to drought.

For those farmers who undertake any adaptation at all, the choice of specific method depends on a number of elements including socio-economic, environmental and institutional factors as well as the economic structure of the country. Thus, the choice of adaptation methods depends on a range of variables which are considered important for the availability, accessibility and affordability of such particular adaptation procedures. Several studies have identified specific variables which may positively or negatively affect the choice of particular adaptation methods. Deressa et al. (2009) conclude that farmers' education level, access to extension and credit, climate information, social capital and agro-ecological settings greatly influence choice while financial constraints and lack of information hinder the farmers' uptake of other adaptation methods. Adesoji and Ayinde (2013) in investigating the methods used by arable farmers to mitigate the negative impact of climate change in Osun State, Nigeria suggest that age, household size, income, source of information and farm size are the main determinants of the choice of adaptation strategies implemented by farmers. In this study the authors mention that the adaptation strategies which are regularly employed are; use of different planting dates, multiple cropping, and cover cropping.

In analysing options and constraints in adaptation in Ethiopia and South Africa, Bryan et al. (2009) insist on a better understanding of climate change by farmers as a way of reducing its negative impacts. That study finds that government farm support, farmers' income, and access to fertile land and credit influence the choice of adaptation methods in South Africa while access to extension and credit, farmers' income and information about climate change influence the choice in Ethiopia. The study further finds that the main barrier to uptake of other adaptation methods in both countries was lack of access to credit.

Each of the studies discussed above has something to offer the big picture. However, as mentioned earlier, what is important for the uptake of adaptation methods is the availability, accessibility and affordability of such techniques. Indeed, many socio-economic variables have been investigated for their impacts on the choice of adaptation methods in different agro-ecological zones. For example, Downing et al. (1997) explore the standard variables to explain adaptation strategies in Africa but investigate specific factors affecting choice of adaptation strategies in the case of specific countries.

In that respect, the current study examines how socio-economic, environmental, and institutional factors as well as the economic structure influence Tanzanian farmers' choice of adaptation methods. Thus, this study includes variables which capture the availability, accessibility and affordability of such techniques for Tanzanian smallholder farmers. The starting points are the following variables identified from the literature: access to credit and extension, farmers' awareness of climate change, knowledge about climate variation and adaptation strategies, availability of capital and improved seeds, availability of water for irrigation, farmers' income, the size of the household, farmers' experience, engaging in non-farm activities, knowledge about adaptation methods, education and gender of the head of the household, livestock ownership, social capital, agro-ecological settings, government farm support, and access to fertile land. Most research cited in this study modelled determinants of the choice of adaptation method using either a probit model or multinomial logit model (Deressa et al. 2009; Bryan et al. 2009; Gbetibouo, 2009). Using MNL as in Deressa et al and Gbetibouo (2009) could be appropriate as the farmers can make the choice from among more than two methods. But this model imposes a very restrictive assumption that the choices of adaptation methods are independent across alternatives, that is, the assumption of Independence of Irrelevant Alternatives (IIA)[40] (Wooldridge, 2001). This assumption is not an easy one because farmers' choice of adaptation methods depends on different factors. In this case the probability of choosing one method over another may change depending on the influence of the dependent factors. Alternatively, this study employs a Multinomial Probit model (MNP) which does not impose the independence assumption and is shown to produce more accurate results than MNL (see for example, Alvarez & Nagler, 1998; Schofield et al. 1998; Alvarez et al. 2000; Dow & Endersby, 2003)[41]. Since there are some choices involved

[40] If the farmer wants to add another adaptation method, the additional choice should not change the relative probability of the existing methods; for example, if the farmer uses irrigation, changing planting dates, or the use of crops which are resistant to drought as adaptation methods; he can add other techniques as well without affecting the probability of continuing using the existing methods, i.e. P_1/P_3 is independent of the remaining probabilities.

[41] This study also employs MNL in order to compare the results with that of MNP. MNP was chosen over MNL results because MNP results are more accurate. Although MNL passes the IIA test we think that the inclusion of several dummy variables in the analysis might influence the estimated coefficients in the Hausman test.

(e.g. crop choice, income), possible sample selection bias needs to be addressed for the proper analysis of the determinants of the choice of adaptation methods. To address the selection bias, this study employ Heckman's two stage estimation (Heckman, 1979) in analysing the likelihood of Tanzanian farmers to adapt to climate change and their choice of adaptation methods.

Table 4.1: Literature Review Summary Table

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
Ishaya and Abaje (2008)	To examine the way indigenous farmers in Jema'a perceive climate change and their adaptation strategies to climate change	200 households	Analysis of variance (ANOVA) and Chi-square	-Indigenous people perceive that the climate has been changing over the years. -The threat of climate change affects health, food supply, biodiversity lost and fuel-wood availability -Lack of improved seeds, access to water for irrigation, current knowledge of modern adaptation strategies, capital, awareness and knowledge of climate change scenarios are the hindering factors for the adoption of modern techniques of combating climate change
Deressa et al. (2009)	To identify the major methods used by farmers to adapt to climate change in the Nile Basin of Ethiopia, the factors that affect their choice of method, and the barriers to adaptation	1000 households	Multinomial Logit (MNL) Model	-The level of education, gender, age, and wealth of the head of household; access to extension and credit; information on climate, social capital, agro-ecological settings, and temperature all influence farmers' choices.
Kabubo-Mariara (2008)	To examine the economic impact of climate change on livestock production in Kenya	722 households	Ricardian model Hadley Centre Coupled Model (HADCM) and Parallel Climate Model (PCM)	-Modest gains from rising temperatures and losses from increased precipitation. - Livestock farmers in Kenya are likely to incur heavy losses from global warming.
Mideksa (2009)	To quantify the general equilibrium impact of climate change on the GDP of Ethiopia	Macro data using a World Bank 2005 SAM	-A multi-sector, multi-product, comparative static small open economy general equilibrium model	Climate change will make the prospect of economic development harder either by reducing agricultural production in the sectors linked to the agricultural sector through 10% decrease in GDP, or by raising the degree of income inequality in which the Gini-coefficient increases by 20%
Bryan et al. (2009)	To examine farmers' perceptions of climate change, the extent of adaptation, barriers to adaptation, and the factors influencing adaptation and adaptation choices.	1800 farm households	-A probit model	-Farm-level adaptation involves more than adopting new agricultural technologies. -The results by country and income terciles suggest that strategies should also be tailored to meet the particular needs and constraints of different countries and groups of farmers.

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
Nhemachena and Hassan (2007)	To examine farmers adaptation strategies to climate change in Southern Africa (South Africa, Zambia and Zimbabwe)	1719 households	-A multivariate discrete choice model	Access to credit and extension and awareness of climate change are some of the important determinants of farm-level adaptation.
Gbetibouo (2009)	-To determine whether the climate has changed, whether the farmers perceive climate change and variability, and what characteristics differentiate farmers who perceived changes from those who do not	794 households	-A Heckman probit model -A multinomial logit (MNL) model	-Household size, farming experience, wealth, access to credit, access to water, tenure rights, off-farm activities, and access to extension are the main factors that enhance adaptive capacity -Lack of access to credit is the main factor inhibiting adaptation
Nzeadibe et al (2011)	-To appraise the perception and understanding of Niger Delta farmers of the role of national governments in climate change governance. -To examine grassroots communities' perception of constraints to adaptation to changing climate	400 households	-Simple descriptive statistics (results presented in tables, figures and charts)	-The major constraints to climate change adaptation by farmers in the Niger Delta are lack of information, low awareness levels, irregularities of extension services, poor government attention to climate problems , inability to access available information, lack of access to improved crop varieties, ineffectiveness of indigenous methods, no subsidies on planting materials, limited knowledge of adaptation measures, low institutional capacity, and absence of government policy on climate change -Farmers have a low level of awareness of government policies/programmes on climate change -Farmers have a poor perception of effectiveness of the policies/programmes and low awareness of the existence and impact of Committees on Climate Change in the National Assembly.
Deressa et al (2011)	-To analyse the two- step process of adaptation to climate change, which initially requires farmers' perception that climate is changing prior to responding to changes through adaptation	1000 mixed crop and livestock farmers	-Heckman sample selection model	-Farmers' perception of climate change is significantly related to the age of the head of the household, wealth, knowledge of climate change, social capital and agro-ecological settings. -Factors significantly affecting adaptation to climate change are: education of the head of the household, household size, whether the head of the household was male, whether livestock were owned, the use of extension services on crop and livestock production, the availability of credit and the environmental temperature.
West et al. (2008)	-To analyse local perceptions and regional climate trends on the central plateau of Burkina Faso	120 people	-ethnographic interviews, focus groups, and participant observation	-farmers perceive that both overall seasonal rainfall and the number of 'big rains' during the rainy season have decreased over the last 30 years - rural households respond to drought by changing their agricultural practices

SOURCE	PURPOSE	SAMPLE	METHODS	RESULTS
Adesoji and Ayinde (2013)	-To identify the mitigation strategies being used by the arable crop farmers; -To determine the factors influencing farmers' mitigation strategies.	120 arable crop farmers	-Multiple Regression Analysis	-Arable crop farmers mitigate change in climate mostly with indigenous or ethno-methods, which do not involve importation of technology in order to sustain production. -When planning extension programs for arable crop farmers age, household size, income, sources of information, and farm size should be considered.
Ajao and Ogunniyi (2011)	-To examine farmers' strategies for adapting to climate change in Ogbomoso agricultural zone of Oyo State of Nigeria.	150 farmers	-Probit model	-The types of climate change identified in the study area were delayed on-set of rainfall, higher temperature and less rain. -The outcome of climate change was food shortage, decline in livestock yield, decline in crop yield and death of livestock. -The identified actions taken to address climate change are growing a new crop, adoption of drought tolerant/resistance crop varieties, diversification from crops to livestock production and new land management practices. -The long-term improvement investments commonly adapted in the study area were tree planting/agroforestry, mulching/surface cover, improved fallowing and fallowing
Ogalleh et al. (2012)	-To present empirical evidence that demonstrates local knowledge, perceptions and adaptations to climate change and variability amongst the smallholders of Laikipia district of Kenya.	-46 transcripts from FGD -206 farmers	-The Palmer Drought Severity Index (PDSI) -Tabulations and frequency tables.	-Climatic variability is increasingly changing -Local perceptions include decreasing rainfalls, increasing temperatures, increasing frosts and increasing hunger -Coping and adaptation strategies used include diversification of crop varieties, migration and sale of livestock.
Below et al. (2012)	-to advance methods related to indices aimed at exploring adaptation processes -to define household level socio-economic variables that potentially explain adaptation -to investigate the socio-economic determinants of adaptation	-299 farmers	-activity-based adaptation index (AAI) -multiple linear regression model	-there are a total of 33 strategies appropriate for adaptation to climate change -public investment in rural infrastructure, a good education system that allows females equal education opportunities, availability of microcredit services, availability and technically efficient use of agricultural inputs, and availability of agricultural extension are the dominant means of improving the farmers' adaptation to climate change in Mlali and Gairo.

4.3 Methods

This section provides an overview of the methodology used in addressing each of the objectives of this study. To reiterate, this study investigates (i) whether smallholder farmers in Tanzania perceive climate change, (ii) whether, as a consequence, they adapt at all in their agricultural activities, and (iii) the factors influencing their choice of adaptation methods. In order to determine whether smallholder farmers in Tanzania perceive climate change, a sample of smallholder farmers were asked whether they have observed variation in the climate across two adjacent decades (i.e. between the 1990s and the 2000s both in terms of the means and variances of precipitation and temperature).

4.3.1 Heckman sample selection model

Farmers make the choice of adaptation methods as they decide to adapt. Since there are some choice variables involved (e.g. crop choice, income) in the farmers' choice, the possible sample selection bias needs to be addressed for the proper analysis of the determinants of this choice. To address possible selection bias, the study employs Heckman's two stage estimation (Heckman, 1979). This study follows the sample selection methodology of Grilli and Rampichini (2006) in which outcome equation consists of multiple choices. The difference between this study and that of Grilli and Rampichini's is that the outcome equation in this study is a multinomial probit model. The choice of a multinomial probit over a multinomial logit model was explained earlier in this study.

Therefore, the selection equation analysing a probability that the farmer adapts to climate change is specified by following a probit model. This follows the assumption that the cumulative distribution of ε_i is normal (Woodridge 2001):

$$p(Y=1|X) = \Phi(X'\alpha) = \int_{-\infty}^{X'\alpha} \frac{e^{-\frac{(X'\alpha)^2}{2}}}{\sqrt{2\pi}} d(X'\alpha) ------------------- (4.1)$$

where Φ is the normally cumulative distribution function. It is assumed that the probability of a farmer undertaking any adaptation at all (Y=1) depends on a vector of independent variables (X), unknown parameters (α), and the stochastic error term (ε) (Gujarati, 2003). The probability of a farmer undertaking any adaptation at all P(Y=1|X)) has been modelled empirically as a function of independent variables such as the experience, gender, education, household income, whether a farmer has observed decadal changes in rainfall and temperature, general availability of information about climate change, agro-ecological zone, and distance from input markets. This model implies a diminishing magnitude of marginal effects for the independent variables and the coefficients give the signs of the marginal effects of each of the independent variables on the probability that the farmer undertakes any adaptation at all. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{n} I_i \ln[\Phi(X'\alpha)] + (1 - I_i)\ln[1 - \Phi(X'\alpha)] \text{--------------------} (4.2)$$

where I_i is the dummy indicator equal to 1 if the farmer i undertakes any adaptation at all to climate change and 0 otherwise. The consistent maximum likelihood parameter estimates are obtained by maximizing the above log likelihood function. The marginal impact for each variable on the probability level is given by:

$$\frac{\partial p(Y=1 \mid X)}{\partial X_k} = \frac{\partial \Phi(Y=1 \mid X)}{\partial X_k} = \phi(X'\alpha)\alpha_k \text{--------------------} (4.3)$$

while the marginal effect for a dummy variable, say X_k, is the difference between two derivatives evaluated at the possible values of the dummy i.e. 1 and 0, Thus,

$$\frac{\partial p(Y=1 \mid X)}{\partial X_k} = [\phi(X'\alpha)]_{j=1} - [\phi(X'\alpha)]_{j=0} \text{------------------------} (4.4)$$

In order to determine the factors influencing the farmers' choice of particular adaptation methods, another probability model is used where the dependent variable is multinomial with as many categories as the number of adaptation methods to climate change available in the sampled population. Thus, when it comes to the choice of a particular adaptation method, the model assumes that farmer i maximises his perceived utility from using a certain adaptation method subject to given factors. In this case, utility is observed through the actions of the farmer in choosing adaptation methods. The farmer's choices are unordered multinomial outcomes. The farmer's choice of one adaptation method from among others is modelled in a random utility framework. The utility function is only partially observed. Following Cameron and Trivedi (2005), the partially observable utility attached to each adaptation method j=0,1,…,J by farmer i can be expressed as:

$$u_0 = \varepsilon_0$$
$$u_1 = X\beta_1 + \varepsilon_1$$
$$u_2 = X\beta_2 + \varepsilon_2$$
$$\ldots.$$
$$u_J = X\beta_J + \varepsilon_J$$

where j=0 indicates that the farmer chooses not to adapt and j=1,2,.,J indicates the available suite of adaptation methods from which farmers can choose; X is a vector of farmers' characteristics and other factors that may affect the farmers' choice of particular methods; β are unknown parameters to be estimated[42] and ε are idiosyncratic factors which are independent from each other. Given the several choices that farmers face, the rule is to choose the adaptation method which gives the highest utility, i.e. if option j gives a farmer the highest utility of all the alternatives then we expect to observe the outcome y = j following that:

$$P(y = j) = \Pr(U_j \geq U_k),\ for\ all\ k$$
$$= \Pr(U_k - U_j \leq 0),\ for\ all\ k$$
$$= \Pr(\varepsilon_k - \varepsilon_j \leq X'_j\beta - X'_k\beta),\ for\ all\ k --------- (4.5)$$

Farmers choose whether to adapt or not, but their choice of adaptation method is influenced by many factors. It has been pointed out that in order to avoid sample selection bias on unobserved variables the units should be sampled randomly so that the unobserved variables should not correlate with the error terms of the statistical model of interest (Copas & Li, 1997). As noted before, the use of a Heckman sample selection model is ideal. After estimating the selection equation using a probit model, the study now estimates the second part of the Heckman model which is an outcome equation that involves the farmers' choice of adaptation method. The probability model for examining the factors influencing farmers' choice of different adaptation methods is the Multinomial Probit (MNP) Model. The use of

[42] ($\beta_J - \beta_5$) for example, shows the net influence of farmers' characteristics and other factors in the choice of adaptation methods.

the MNP Model is needed because farmers have to choose from many adaptation methods which are unordered and nominal in character (Bartels et al., 1999; Greene, 2000; Wooldridge, 2001; Gujarati 2003).[43] In MNP it is assumed that the error term follows a multivariate normal distribution in which each error has a zero mean and the errors are allowed to be correlated. As it is, MNP models' direct evaluation of the likelihood entails a large number of integrals (one for each observation) of moderate dimension. The omitted outcome in the multinomial model is not adapting (not adapting is considered as one of the choices that farmers are expected to make). The assigning of not adapting as omitted outcome is because (i) it is easy for any farmer to decide to choose not to adapt even though they have the ability and have access to other adaptation methods; and (ii) it is the most frequently occurring outcome. From equation (4.5) the probability that alternative j is chosen equals

$$\Pr(y=j)=\Pr\{\varepsilon_k-\varepsilon_j\leq(X_j-X_k)'\beta,\ for\ all\ k\text{--------}(4.6)$$

Where X's are alternative-specific regressors and εs are multivariate normally distributed (Cameron and Trivedi, 2005).

The inverse Mill's ratio (IMR) calculated after the first stage selection equation (the probability of adapting to climate change) is included in the second stage multinomial probit model as one of the predictors (a correcting term). The significance of IMR indicates the existence of selection bias though if it is not significant this does not necessarily imply that there is no selection bias.

4.3.2 Description of Variables and Data sources

From a review of the relevant literature, a set of variables was identified which might be important in explaining the uptake of adaptation to climate change in general, as well as the choice of specific adaptation methods. These include socio-economic factors, environmental factors, institutional factors, and the economic structure in which the choices occur.[44]

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[43] The farmers' realities which define their needs and aspirations (i.e. contextual background) shape their decisions on how to adapt to climate change. Thus, the choice of a particular adaptation method is subject to contextual backgrounds. For this study, the contextual background includes socio-economic factors, environmental factors, institutional factors, and the economic structure.

[44] Our starting point was the following variables: access to credit and extension, farmers' awareness about climate change, knowledge about climate change and adaptation strategies, availability of capital and improved seeds, availability of water for irrigation, farmers' income, the size of the household, farmers' experience, engaging in non-farm activities, knowledge about adaptation methods, education and gender of the head of the

Socio-economic variables

Key socio-economic variables are household consumption and household income, both farm income derived from selling farm products and non-farm income derived from other non-farm activities including incomes from small businesses (e.g. kiosks), wages, and other non-farm incomes. Household income is expected to be positively related to undertaking adaptation to climate change, that is, the more income the farmer has, the more likely it is they will undertake adaptation. Non-farm income is also relevant here because farmers generally finance adaptation from their overall incomes regardless of source.

Another key variable is awareness about climate change and adaptation methods, that is, whether farmers are informed about climate change and various adaptation techniques. Such information may be obtained from media sources i.e. radio, television, or newspapers. Being aware of climate change and the different adaptation methods gives a farmer a wide range of options for response and allows them to choose those methods which are personally more convenient.

The farming experience of the household head is expected to be positively related to undertaking adaptation. A farmer with more experience would know when climate change is occurring in the area and which methods work well in that specific agro-ecological zone. The selection of particular crops to be grown as the household's major crop is also an important factor in choosing certain adaptation methods. Large households are expected to offer more of the technical and manual skills required to respond to climate change. Higher educational credentials of the household head and any other member of the household with the highest education increase the knowledge base.

Environmental variables

The environmental variables used in this study are incidences of droughts and floods, agro-ecological zones, the farmer's observation of changes in rainfall and temperature, and the average annual rainfall and temperature for the respective regions under study. These variables are important as they help give concrete signs of climate change at the farm level. Farmers who experience changes in rainfall and temperature, including increasing droughts and floods are more likely to adapt to climate change. The location of plots in certain agro-ecological zones influences the adaptation modes used.

household, livestock ownership, social capital, agro-ecological settings, government farm support, access to fertile land.

Institutional variables

Institutional factors include all social mechanisms of interaction, which are used to manage adaptation to climate change. These mechanisms include the regulations, enforcement and agricultural extension, which determine access to adaptation. Government intervention is of great importance here especially now that Tanzania is implementing the "Kilimo Kwanza" policy which seeks to promote sustainable growth in the agricultural sector. However, the presence of social capital within the farming communities is probably more important. Farmers can receive technical support about adaptation to climate change from both the government and community groups.

The economic structure

The national economic structure is an important determinant of the uptake of adaptations to climate change. Here, the economic structure includes the market conditions governing agricultural activity and other economic alternatives. For example, farm size, access to formal and informal credit[45], distance from inputs and output markets will affect agricultural productivity and the uptake of adaptation techniques. This investigation uses the same dataset discussed in Chapter Three. Since this study is about perception of climate change in the past 20 years, the 22 households with household heads younger than 30 years were dropped from the sample. Those household heads are perceived to be too young to remember what had happened when they were less than 10 years old. In this case, this study uses the information provided by 534 households. The descriptive statistics of the explanatory variables which will be used in the analysis are presented in Table 4.2.

Table 4.2: Descriptive Statistics of Explanatory Variables to be used in the Analysis

Variable	Mean	Std. Dev.	Min	Max
Annual household income (in '000 TZS[46])	5260.92	3016.63	9100	24500
Age of the head of household (years)	46.80	12.25	30	96
Head of household is male (male=1, female=0)	0.75	0.40	0	1
Household has access to media (yes=1, no=0)	0.79	0.40	0	1
Highest education in the household (years)	10.21	3.08	0	19
Number of years worked as farmer (years)	22.71	12.97	1	70
Size of the household (numbers)	6.47	3.48	1[47]	17

[45] Informal credit here refers to borrowing from relatives or neighbours.

[46] The exchange rate being 1USD = 1592 TZS, January 2012.

Variable	Mean	Std. Dev.	Min	Max
Farm size (hectares)	1.92	0.75	0.5	3
Frequency experienced floods in the past 20 years (years)	1.42	1.19	0	6
Frequency experienced drought in the past 20 years (years)	2.61	2.07	0	10
Average rainfall in household's neighbourhood in 2010 (millimeter)	874.55	250.51	583	1370.7
Average temperature in household's neighbourhood in 2010 (degrees centigrade)	24.10	2.34	21	27.07
Has received agricultural technical support from community group or government (yes=1, no=0)	0.57	0.49	0	1
Grows rice as the major crop (yes=1, no=0)	0.06	0.24	0	1
Grows sorghum as the major crop (yes=1, no=0)	0.13	0.33	0	1
Has observed changes in rainfall and temperature (yes=1, no=0)	0.99	0.11	0	1
Access to credit (yes=1, no=0)	0.49	0.50	0	1
Distance from input markets (kilometres)	5.84	4.34	0.5	11
Located in the Coastal agro-ecological zone (yes=1, no=0)	0.27	0.44	0	1
Located in the Arid agro-ecological zone (yes=1, no=0)	0.06	0.26	0	1
Located in the Alluvial agro-ecological zone (yes=1, no=0)	0.27	0.44	0	1
Located in the Southern highlands agro-ecological zone (yes=1, no=0)	0.07	0.26	0	1
Located in the Semi-arid agro-ecological zone (yes=1, no=0)	0.09	0.29	0	1
Located in the Plateau agro-ecological zone (yes=1, no=0)	0.23	0.46	0	1

***Source:** Own survey data, December 2010-January 2011*

4.4 Results and Discussion

Farmers were asked to compare the climate in the two decades between the 1990s and the 2000s with respect to mean and variance precipitation and temperature. Five hundred and twenty eight farmers (98.9%) perceived mean and variance changes in both precipitation and temperature. On the one hand, mean precipitation was perceived to have decreased while the variance of precipitation had increased. On the other hand, both the mean and variance of temperature were perceived to have increased. In fact, 531 farmers (99.46%) perceived climate changes either with respect to precipitation or temperature. Only 3 farmers (0.54%) did not perceive any climate change. The research therefore indicates overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades.

[47] 15 households have one household member. Most of them are female unmarried (widowed or not married at all) aged between 45 and 56 years, whose children have started their own families.

It is necessary to know whether farmers' perceptions are consistent with reality. If their perceptions deviate from fact then there is a risk that they might not respond at times when they should be responding. Even though climate change is a rather long term phenomenon, there seems to be evidence that this has been occurring in the study areas across the two decades in question.[48] Statistical evidence from data provided by Tanzania Meteorological Agency shows a decrease in mean decadal rainfall from 847.3 mm in the 1990s to 763.5 mm in the 2000s and an increase in mean decadal temperature from 23.20°C in the 1990s to 23.8°C in the 2000s; as well as an increase in the decadal variances of both rainfall and temperature, that is, the rainfall decadal variance rose from 8476.08 in the 1990s to 41934.1 in the 2000s and the temperature decadal variance rose from 7 in the 1990s to 8 in the 2000s.

The rainfall data from TMA is then segmented into 2 seasons; long rains (Masika) and short rains (Vuli)[49]. Statistical evidence still shows a decrease in decadal mean rainfall in both Vuli and Masika rain seasons. While the mean rainfall in Vuli seasons decreased from 274.3 mm in the 1990s to 244.2 mm in the 2000s, the mean rainfall in Masika seasons decreased from 558.2 mm in the 1990s to 442.5 mm in the 2000s. The surprising result is the decadal rainfall variance in the Vuli season. Generally, the science of climate assumes that precipitation variability increases with an increase in temperature. Statistical evidence shows that the decadal rainfall variance in Masika seasons increased from 10056.5 in the 1990s to 17149.7 in the 2000s and in the Vuli seasons the variance decreases from 54190.6 in the 1990s to 20360.1 in the 2000s. The decrease in rainfall variance was also found by Sun et al. (2012) when analysing the global monthly mean precipitation. In their study they argue that this variability of rainfall patterns leads to a redistribution of rainfall in which dry seasons get wetter and wet seasons get drier. Thus, farmers' perceptions about climate change are consistent with reality and, therefore, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential agricultural losses.

Now that we have found evidence that Tanzanian smallholder farmers perceive climate change to be occurring in their areas, we proceed to investigate the other two objectives of the study. This includes investigating whether, as a consequence of their perceptions about

[48] Increases in temperature affects crop yield, and this assumption is supported by Watson et al. (1998) who point out that when the crops are at high levels of temperature tolerance, a small increase in temperature will affect the yield badly. In line with temperature, an increase/decrease in rainfall above/below the required amount leads to reduction in yields.

[49] According to our sampled agro-ecological areas only Tanga and Morogoro regions have bimodal rainy seasons. They have short rainy seasons in October to December and long rainy seasons in March to June.

climate change, they attempt to adapt at all, and investigating the factors influencing their choice of adaptation methods. Multicollinearity tests were performed in order to check whether independent variables in the models to be estimated do not provide redundant information about the response variables. We tested for the presence of multicollinearity using the Variance Inflation Factor, $VIF_j=1/(1-R^2_j)$ where R^2_j is the coefficient of determination of the model which includes all independent variables except the j^{th} variable. Table 4.3 below demonstrates that the VIF for all variables which are less than 10. This indicates that we can conclude that there is no problem with multicollinearity.

Table 4.3: VIF Test for Multicollinearity

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond Index	R-Squared
Annual household income	2.02	1.42	0.496	3.871	1.	0.504
Household has access to media	1.04	1.02	0.964	2.403	1.269	0.035
Number of years worked as farmer	1.24	1.11	0.809	1.805	1.464	0.191
Head of household is male	1.12	1.06	0.894	1.436	1.642	0.105
Size of the household	1.39	1.18	0.718	1.337	1.701	0.281
Highest education in the household	1.41	1.19	0.707	1.201	1.795	0.293
Farm size	1.08	1.04	0.925	1.127	1.853	0.075
Frequency experienced floods in the past 20 years	1.14	1.07	0.879	0.974	1.993	0.120
Frequency experienced drought in the past 20 years	1.34	1.16	0.747	0.960	2.008	0.253
Average rainfall in household's neighbourhood in 2010	6.27	2.50	0.159	0.893	2.082	0.841
Average temperature in household's neighbourhood in 2010	4.61	2.15	0.217	0.862	2.118	0.783
Has received technical support	1.57	1.25	0.635	0.772	2.238	0.364
Grows rice as the major crop	1.78	1.33	0.568	0.693	2.362	0.437
Grows sorghum as the major crop	2.03	1.43	0.497	0.688	2.371	0.508
Has observed changes in rainfall and temperature	1.06	1.03	0.949	0.480	2.839	0.058
Access to credit	1.39	1.18	0.725	0.433	2.988	0.279
Distance from input markets	1.97	1.40	0.508	0.392	3.140	0.492
Located in the Coastal agro-ecological zone	7.83	2.80	0.127	0.312	3.517	0.872
Located in Plateau agro-ecological zone	5.14	2.27	0.197	0.175	4.692	0.805
Located in the Alluvial agro-ecological zone	4.52	2.13	0.223	0.105	6.049	0.779
Located in the Southern highlands agro-	2.29	1.51	0.436	0.071	7.367	0.564

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond Index	R-Squared
ecological zone						
Located in the Semi-arid agro-ecological zone	5.83	2.41	0.172	0.032	9.065	0.828

Note: *Mean VIF 2.49; Condition Number 7.3669; Determinant of correlation matrix 0.0004*

Here we report the probit estimation results for (i) the probability of adapting to climate change in general, and (ii) the multinomial probit estimation results for the probability of using short season crops, using crops resistant to drought, irrigating, changing planting dates and planting trees relative to not adapting. In both models the marginal effects of the independent variables are reported. Table 4.4 reports the marginal effect results for the selection and outcome equations.[50] The results for the binary probit model (selection equation) are reported in column 7 while the results of outcome equations that represent each dominant adaptation method chosen by farmers are reported in columns 2 to 6. The log-likelihood ratios test in all the equations strongly rejects the null hypothesis: we therefore conclude that the variables included in the model explain the variation in the regressand. Finally, the results on the inverse Mill's ratios suggest a strong selection mechanism in choosing short season crops, crops resistant to drought and changing planting dates. It was important, therefore to address the sample selection issue. The coefficients -0.569, -0.546 and 0.326, suggest that, on average, unobservable factors that increase the probability of farmers adapting to climate change decreases their likelihood of choosing to plant short season crops and change planting dates, and increases their likelihood of planting crops resistant to drought, respectively.

The Heckman sample selection model has the limitation that different variables might determine participation and outcomes. The independent variables in selection and outcome equations are not mutually exclusive; there are some variables that are included in both equations but there are some variables that are not included in the outcome equation. This is because the outcome equation is performed after selection equation and the variables that are necessary in the participation equation might not be necessary determinants in the outcome

[50] The coefficient results for the Heckman sample selection model are reported in table 4.6 (see Appendix 4.1). We also performed Heckman sample selection using Multinomial Logit model as an outcome equation. We wanted to compare the MNL model with that of MNP and make a conclusion on which model should be used. As explained before, our MNL also passed the IIA assumption but because of the reasons explained earlier in this chapter, it was decided to use MNP for our analysis. The results for both the Heckman model with MNL and IIA test are provided in the Appendix.

equation because the household is already participating. In this study, the dummies for the fact that the farmer has observed changes in rainfall and temperature and for distance from input markets, are excluded from the outcome equation. It is important to include the variable that captures the impact of observing changes in rainfall and temperature to determine the probability of a farmer adapting to climate change but observing changes does not necessarily determine the adaptation method implemented.

The results of the selection probit model (column 7) suggest that the probability of a typical Tanzanian farmer adapting to climate change increases with education levels of household members, farmers observing climate change with respect to precipitation and temperature across the two decades, the frequency of drought[51] experienced during the past 20 years, and growing rice as the major crop. The results also suggest that the probability of adapting to climate change decreases with temperature and rainfall levels in the farming area and distance from input market. Farmers located in the coastal and plateau agro-ecological zones tend to use adaptation strategies more than those located in the arid agro-ecological zone.

The probit model parameters are estimable up to a scaling factor. The coefficients of the probit model give the change in the mean of the probability distribution of the dependent variable associated with the change in one of the explanatory variables, but these effects are usually not of primary interest. The marginal effects on the probability of possessing the characteristic can be of more use. The marginal effects vary across individuals and, in this case, indicate by how much the probability of a farmer using adaptation measures alters with changes in the explanatory variables.

The marginal effect for having observed changes in rainfall and temperature across the two decades is 43.9 percent. This implies that farmers who have observed climate change with respect to precipitation and temperature across the past two decades have a 43.9 percent higher probability of adapting to climate change above the base case. This result is largely expected because respondents were asked about the adaptation which was undertaken in response to observing climate change. It is nevertheless necessary to test this variable as the model in Table 4.4 is run using data from all respondents, a few of whom did not perceive change to be occurring. The results seen so far with respect to this variable are very important because they provide two confirmations: first, farmers perceive that climate change is occurring; and, second, farmers respond to their perception of this phenomenon by

[51] In this study, drought means experiencing less rain than usual.

undertaking adaptation measures. Therefore, the major role that the Tanzanian government needs to occupy itself with relating to the effects of climate change on smallholder agriculture is simply to assist them to overcome the constraints they face; namely shortage of water, funds and seeds, and poor planning.[52]

With respect to education, farmers with more education or in the households with more educated members are more likely to pursue adaptation strategies related to climate change than farmers with lower education levels or in households with members with lower levels of education. On average, one more year of schooling of the household member with the most years of education increases the probability of adapting to climate change by 2.2 percent. These results have also been reported by the empirical studies of Deressa et al. (2008), Goulden et al. (2009), and Iglesias et al. (2011).

On average, a 1 degree increase in the average annual temperature in the farmer's neighbourhood decreases the probability of farmers adapting by 5.5 percent. This is a plausible result for crops requiring a higher temperature. At the same time, a 1 mm increase in average annual rainfall in the farmer's neighbourhood decreases the probability of adaptation by 0.1 percent. This seems plausible because most of the adaptation methods that Tanzanian farmers adopt are aimed at dealing with insufficient rainfall. This means that in the time when there is shortage of rainfall, there is a need for smallholder farmers to adapt to the falling rainfall availability by implementing either water preserving technologies or planting crops that do not need much rainfall, for example sorghum, potatoes and cassava.

The probability of farmers who grow rice as their major crop adapting is 31 percent higher than for those who grow other major crops including maize. This might be because rice is among the most popular cereal crops in Tanzania and is the preferred foodstuff for many people with medium and high income. In this case farmers who grow rice as their major crop might do anything to adapt to climate change so as to ensure good yields. Distance from input markets reduces the probability of farmers adapting. The results show that a 1 kilometre increase in distance from input market reduces this probability by 1 percent. This is because when input markets are located far from farming plots it is difficult for farmers to access the inputs necessary for adaption. Farmers who reported to experience one additional year of drought have a 3 percent higher probability of adapting. Farmers located in the coastal and

[52] The government might also want to promote specific adaptation methods and not others. This issue will be picked up later on during a discussion about specific adaptation methods.

plateau agro-ecological zones are 54.1 and 28 percent more likely to adapt respectively than those who reside in the arid zone.

The results from the multinomial probit model show the direction and the magnitude of the effect of different factors influencing farmers' choice of a particular adaptation method from up to five alternative adaptation methods used by Tanzanian farmers.

Short-season crops

The results for Method 1 suggest that the probability of using short-season crops relative to no adaptation increases with temperature intensity, agricultural technical support from community groups and/or government, and location in the coastal agro-ecological zone and decreases if farmers grow rice as their major crop.

Farmers generally use short-season crops when temperatures increase. An increase in the average annual temperature has an impact on farmers' adaptation to climate change using short-season crops because a 1 degree centigrade increase in average annual temperature leads to a 8.2 percent increase in the use of short-season crops. Receiving agricultural technical support from either the government and/or community groups increases the farmers' probability of using short season crops by 9.9 percent. Empirical studies recognise the importance of the mentioned extension services to farmers, for example; Ziervogel et al. (2006), Cooper et al. (2008), Keil et al. (2008), Deressa et al. (2008), and Below et al. (2012).These studies confirm the importance of agricultural extension services provided by government and community groups.

Farmers who grow rice as their major crop have a 27.1 percent lower likelihood of using short-season crops compared to their peers growing other major crops. Farmers located in the coastal zone are 2.2 percent more likely to use short-season crops compared to their peers in the arid agro-ecological zone.

Crops resistant to drought

The results for Method 2 imply that the probability of using crops which are drought resistant relative to no adaptation attempts increases with an increase in the level of education of the household, temperature intensity, and incidence of drought; and decreases with agro-ecological zones.

An increase in average annual temperature appears to impact on the decision of farmers to use crops which are drought resistant as the study indicates that a 1 degree centigrade increase in average annual temperature above the 2010 level leads to a 4.9 percent increase in the use of such crops. This result is plausible; it is expected farmers will choose planting more drought resistant crops when temperatures are high because those crops can tolerate the high temperature. Farmers who are more educated and those households with more educated members tend to use drought resistant crops more often. On average, an increase in one more years of education increases the probability of farmers using drought resistant crops as opposed to not attempting such adjustment. It is expected that farmers who have reported to experience more incidence of drought in the past 20 years would want to plant drought resistant crops. The results tell us that an increase in the number of years that a farmer reported to experience drought increases the probability of the use of such crops by 1.9 percent.

Being located in the coastal, alluvial plains, southern highlands, and semi-arid zones decreases the likelihood of farmers' using crops which are resistant to drought by 1.4 percent, 23.5 percent, 21.2 percent, and 16.9 percent respectively compared to farmers located in the arid agro-ecological zone.

Irrigation

The results from Method 3 show that the likelihood of using irrigation relative to no adaptation increases with rainfall intensity and being located in alluvial plains, southern highlands, and semi-arid agro-ecological zones, and decreases for farmers growing rice as the major crop.

Our results confirm that smallholder farmers in the lowland areas of Tanzania grow rice because in these areas they do not need to irrigate their plots. Farmers who grow rice as the major crop are 3.4 percent less likely to irrigate their plots.

An increase in average annual rainfall does not considerably impact farmers' adaptation to climate change using irrigation because a 1 millimeter increase in average annual rainfall above the 2010 level only leads to a 0.02 percent increase in the use of irrigation. Being located in alluvial plains, southern highlands, and semi-arid agro-ecological zones increase the probability of the use of irrigation by 50.7 percent, 60.4 percent, and 40.8 percent respectively compared to farmers located in the arid agro-ecological zone. This may be simply explained by the fact that water for irrigation can be more easily available in any other agro-ecological zone than in the arid zone. In this case, farmers who are capable of irrigating their plots can easily use this adaptation method providing they are not residing in arid agro-ecological zone.

Changing planting dates

The results from Method 4 suggest that the likelihood of changing planting dates relative to no adaptation increases with incidences of flood but decreases with highest education in the household, rainfall intensity, access to information, access to credit, incidence of drought, and being located in the semi-arid and southern highlands agro-ecological zones.

The probability of farmers changing planting dates decreases in relation to education in the household. An additional year of education for the household member with the highest education level decreases the probability of the household's changing planting dates as their adaptation method by almost 2 percent compared to the base category. The probable reason for the negative relationship might be the fact that farmers who rely on rainfall in their agricultural activities plant their seeds when rain starts. They do not need to be educated to see that the rainfall season has started. Rainfall intensity does not have much impact on the probability of farmers changing planting dates. The results show that a 1 millimetre increase in rainfall decreases the likelihood of farmers changing planting dates by 0.03 percent. The results reveal that farmers who have access to media are 7.7 percent more likely to change planting dates compared to those who do not have access to media. Farmers who have access to the media receive information from weather forecasts to aid their decision on when to plant their crops.

The marginal effect for credit of -0.099 suggests that changing planting dates is an adaptation method predominantly suitable for those lacking access to credit. Access to credit increases the probability of farmers switching away from changing planting dates by almost 10 percent. Presumably with access to capital, farmers would use other capital-intensive adaptation methods. This implies that lack of access to credit is a significant constraint preventing some farmers from using methods other than shifting planting dates. Financial institutions such as banks, Savings and Credit Cooperative Society (SACOS) and Village Community Banks (VICOBA) are therefore potentially effective institutions in empowering farmers to reduce the impact of climate change using adaptation methods they deem suitable. In the same way, this also suggests the importance of informal networks including relatives, friends, and neighbours in credit provision for agricultural investments.

Findings are that farmers who reported to experience more incidence of drought have a 2.7 percent less probability of changing planting dates. However, farmers who reported to experience less incidence of flood are 2.4 percent more likely to shift dates. When there is drought, changing planting dates might not be a favourable choice for farmers. Whether the plants are planted early or later might not change the fact that the area is dry and therefore not conducive to agriculture. Being located in southern highland and semi-arid zones decreases the likelihood of farmers changing planting dates by 7.6 percent and 8.7 percent respectively compared to those located in the arid agro-ecological zone.

Planting trees

The results from Method 5 show that the probability of planting trees as an adaptation method to climate change relative to no adaptation decreases with growing rice as a major crop and with rainfall intensity.

The results reveal that farmers who grow rice as their major crop have a 49.5 percent lower probability of planting trees as their adaptation method. This can be explained by fact that trees attract birds which may then eat the rice in the fields thus endangering the crop yield. The results further reveal that a one millimetre increase in average annual rainfall decreases the probability of farmers planting trees by 0.01 percent. Planting trees is associated with attracting rainfall in the area, it is logical that when rainfall increases in a certain area the farmers might not choose to use that adaptation technique.

Table 4.4: Marginal effects Heckman Sample selection model

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					**Selection equation: Probability to adapt**
Explanatory variable	**Method 1** Short season crops	**Method 2** Crops resistant to drought	**Method 3** Irrigation	**Method 4** Changing planting dates	**Method 5** Planting trees	
Annual household income	-0.035 (0.054)	0.059 (0.047)	0.012 (0.019)	0.011 (0.03)	0.002 (0.011)	0.074 (0.054)
Number of years worked as farmer	0.001 (0.002)	-0.003 (0.002)	-0.001 (0.001)	0.001 (0.001)	0.0002 (0.0004)	-0.001 (0.002)
Farm size	0.043 (0.03)	-0.007 (0.024)	-0.004 (0.01)	-0.012 (0.016)	-0.015 (0.012)	-0.04 (0.029)
Highest education in the household	-0.009 (0.01)	0.023** (0.008)	0.005 (0.004)	-0.019*** (0.005)	0.004 (0.003)	0.022*** (0.008)
Size of the household	0.001 (0.007)	-0.001 (0.006)	-0.002 (0.002)	0.002 (0.004)	0.001 (0.001)	-0.0002 (0.007)
Average temperature in the neighbourhood in 2010	0.082*** (0.017)	0.049** (0.018)	-0.005 (0.006)	-0.01 (0.009)	-0.011 (0.007)	-0.055*** (0.02)
Average rainfall in the neighbourhood in 2010	-0.00001 (0.0002)	0.0002 (0.0002)	0.0002*** (0.0001)	-0.0003** (0.0001)	-0.0001** (0.0001)	-0.001*** (0.0003)
Head of household is male#	-0.004 (0.053)	0.028 (0.044)	-0.009 (0.019)	-0.029 (0.033)	0.01 (0.01)	0.042 (0.051)
Household has access to media#	0.032 (0.053)	0.019 (0.046)	0.017 (0.015)	0.077* (0.042)	0.021 (0.018)	0.061 (0.053)
Access to credit#	0.037	0.041	-0.003	-0.099**	0.021	0.039

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					Selection equation: Probability to adapt
Explanatory variable	**Method 1** Short season crops	**Method 2** Crops resistant to drought	**Method 3** Irrigation	**Method 4** Changing planting dates	**Method 5** Planting trees	
	(0.051)	(0.044)	(0.015)	(0.028)	(0.018)	(0.049)
Frequency of experienced drought in the past 20 years#	0.001 (0.013)	0.019* (0.012)	0.003 (0.004)	-0.027*** (0.009)	0.006 (0.004)	0.030*** (0.012)
Frequency experienced flood in the past 20 years#	-0.02 (0.019)	-0.017 (0.019)	0.007 (0.006)	0.024** (0.009)	-0.004 (0.004)	-0.015 (0.019)
Has received technical support#	0.099** (0.051)	-0.019 (0.044)	-0.022 (0.019)	-0.027 (0.031)	-0.002 (0.009)	0.015 (0.052)
Grows rice as the major crop#	-0.271*** (0.032)	-0.059 (0.108)	-0.034** (0.013)	0.079 (0.149)	-0.495** (0.245)	0.31*** (0.058)
Grows sorghum as the major crop#	-0.083 (0.075)	-0.072 (0.067)	0.346 (0.235)	-0.041 (0.036)	-0.001 (0.013)	0.038 (0.087)
Located in the Coastal agro-ecological zone#	0.022*** (0.109)	-0.014** (0.006)	0.001 (0.002)	-0.003 (0.004)	-0.003 (0.003)	0.541*** (0.082)
Located in the Plateau agro-ecological zone#	-0.069 (0.094)	-0.089 (0.057)	0.142 (0.126)	-0.04 (0.079)	0.127 (0.13)	0.28*** (0.067)
Located in the Alluvial plains agro-ecological zone#	-0.028 (0.109)	-0.235*** (0.042)	0.507** (0.173)	-0.037 (0.034)	-0.0003 (0.013)	-0.027 (0.094)
Located in the Southern highlands agro-ecological zone#	-0.063 (0.142)	-0.212*** (0.022)	0.604** (0.237)	-0.076** (0.018)	0.027 (0.045)	0.003 (0.115)
Located in the Semi-arid agro-ecological zone#	0.129	-0.169***	0.408*	-0.087***	-0.009	0.008

	Outcome equation: Choice of adaptation method; a Multinomial Probit model					Selection equation: Probability to adapt
Explanatory variable	**Method 1** **Short season crops**	**Method 2** **Crops resistant to drought**	**Method 3** **Irrigation**	**Method 4** **Changing planting dates**	**Method 5** **Planting trees**	
	(0.197)	(0.044)	(0.246)	(0.023)	(0.014)	(0.135)
Distance from input markets						-0.01* (0.007)
Has observed changes in rainfall and temperature#						0.439** (0.182)
Inverse Mill's Ratio	**-0.569*** (0.172)**	**0.326** (0.138)**	**0.039 (0.071)**	**-0.546*** (0.109)**	**-0.101 (0.063)**	
Number of Observations (543)	**131**	**93**	**31**	**60**	**37**	**534**
Base rate	**0.2559**	**0.186**	**0.0351**	**0.0784**	**0.0141**	**0. 67341149**

Note:

- *Base category for adaptation methods is "No adaptation"*
- *Base category for agro-ecological zone is Arid*
- *Standard errors are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

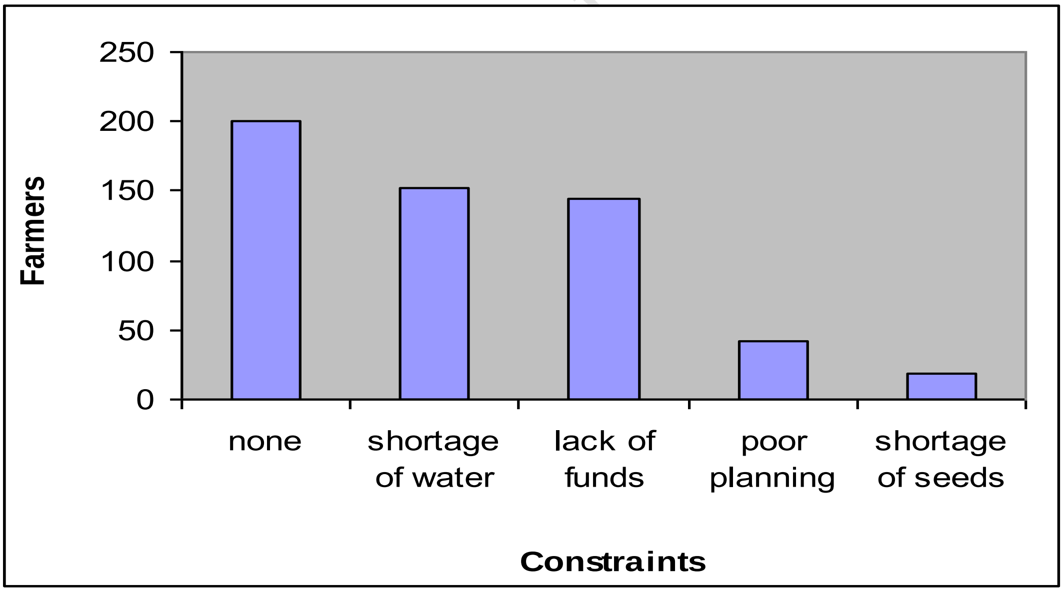
Undertaking some adaptation to climate change is a step in the right direction by farmers in Tanzania. However, some adaptation techniques are more effective than others. Particular adaptation methods might be more appropriate for particular crops or agro-ecological zones. The government can play a significant role by promoting adaptation methods appropriate for particular circumstances. In order for this to occur, the government would require information about the key drivers of the current choice of adaptation methods. This information gives two useful hints: the social characteristics of farmers who are likely to voluntarily adopt particular adaptation methods, and the environmental, institutional and economic conditions influencing their adoption of particular methods. The first type of information gives guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation by using particular methods. The second set of information provides guidance about the environmental, institutional and economic conditions which need to be changed to promote particular adaptation methods. On the basis of the above information about the drivers of specific adaptation methods, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances. The above results assist in targeting farmers' recruitment into initiatives aimed at enhancing adaptation using particular methods as well as guidance about the environmental, institutional and economic conditions which need to be targeted to promote these specific methods. As shown in Table 4.5, about 34 percent of surveyed farmers did not undertake any adaptation at all even though these adaptations are not necessary for only about 10 percent of the surveyed farmers. Thus, a sizeable number of farmers who are currently not making changes ought to be doing so. In many cases, farmers are generally constrained from undertaking these adaptation measures. In the absence of constraints, more farmers would opt for irrigation (28.1 percent instead of the current 5.6 percent), planting short season crops (27 percent instead of the current 24.1 percent), and planting trees (11.7 percent instead of the current 7.4 percent). Thus irrigation is the dominant adaptation method that farmers would ideally want to use to respond to observed climate change but currently they are constrained by circumstances.

Table 4.5: Perceived best and implemented adaptation methods to climate change

Adaptation Method	Perceived Best By	Implemented By
Irrigation	156 farmers, 28.1%	31 farmers, 5.6%
Short season crops	147 farmers, 27.0%	131 farmers, 24.1%
Crops resistant to drought	83 farmers, 15.5%	93 farmers, 17.3
Planting trees	61 farmers, 11.7%	37 farmers, 7.4%
Changing planting dates	38 farmers, 7.4%	60 farmers, 11.3%
No adaptation	49 farmers, 10.4%	182 farmers, 34.4%

Source: *Own survey data, December 2010-January 2011*

The reasons given by farmers for not using adaptation methods perceived to be the best in dealing with climate change include lack of funds (144 farmers, 25.9 percent), shortage of water (152 farmers, 27.3 percent), poor planning (42 farmers, 7.6 percent), and shortage of seeds (18 farmers, 3.2 percent) as shown in Figure 4.1.



Source: *Own survey data, December 2010-January 2011*

Figure 4.1: Constraints to implementing the best perceived adaptation methods

4.5 Policy implications and Conclusions

The main purpose of this study was threefold: (i) to investigate whether smallholder farmers in Tanzania perceive climate change, (ii) to investigate whether, as a consequence, they adapt at all in their agricultural activities, and (iii) to investigate the factors influencing their choice of particular adaptation methods. The study collected data from 556 randomly selected smallholder farming households from four representative administrative regions representing six of the seven agro-ecological regions of the country. Farmers were asked to compare their perceptions of the climate in the decade between the 1990s and the 2000s with respect to mean and variance precipitation and temperature. Among them, 22 household heads were below 30 years. In these cases we dropped them in our analysis for the reason that they might not remember what happened when they were 10 years old or younger. There is overwhelming evidence that Tanzanian smallholder farmers perceive climate change to have occurred over the past two decades (i.e. 1990s-2000s). Even though climate change is a long term phenomenon, statistical evidence from data provided by the Tanzania Meteorological Agency provides evidence that climate change has indeed been occurring in the study areas across the two decades in question. Thus, farmers' perceptions about climate change are consistent with reality and, therefore, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential losses from the effects of climate change on this vulnerable group.

Those farmers who perceive climate change adapt to it in their agricultural activities. The results show that farmers who perceived climate variation with respect to precipitation and temperature across the past two decades have a 43.9 percent higher probability of adapting. The results of the binary probit model used as selection equation in the Heckman sample selection model of a famer's decision to use adaptation measures suggest that the probability of undertaking any adaptation increases with household education levels, having observed climate change with respect to precipitation and temperature across the two decades, the frequency of drought experienced during the past 20 years, growing rice as the major crop, and the agro-ecological zone of the farm. The results also suggest that the probability of undertaking adaptation decreases with temperature and rainfall levels in the farming area, and the distance from input markets. Farmers located in the coastal and plateau agro-ecological zones tend to undertake more adaptation compared to those located in the arid agro-ecological zone.

Farmers mentioned planting short-season crops and crops which are resistant to drought, using irrigation, changing planting dates and planting trees as the methods they use to deal with the change. The study used a multinomial probit model as the outcome equation in the Heckman sample selection model to investigate the factors influencing farmers' choice of specific adaptation methods. The probability of using short-season crops increases with temperature intensity, having received agricultural technical support from community groups and/or government, and being located in the coastal agro-ecological zone; and decreases with growing rice as the major crops. The probability of using crops which are drought resistant increases with household education levels, temperature intensity, and incidence of drought, and decreases with location in the coastal, alluvial plains, southern highland, and semi-arid agro-ecological zones. The probability of using irrigation increases with rainfall intensity, and residing in alluvial plains, southern highland and semi-arid agro-ecological zones, and decreases with growing rice as the major crop. The likelihood of changing planting dates increases with the incidence of flood but decreases with household education levels, rainfall intensity, access to the media, incidences of drought, access to credit, and location in semi-arid or southern highland agro-ecological zones. The probability of planting trees as an adaptation method decreases with growing rice as the major crop and with rainfall intensity. The inverse Mill's ratio shows that there is sample selection in three adaptation choices. In this case, it was important to address the possibility of endogeneity bias.

The first and foremost role that the Tanzanian government needs to occupy itself with surrounding the effects of climate change on smallholder agriculture is to assist smallholder farmers to overcome the constraints they face. The results offer guidance with respect to the environmental, institutional and economic conditions which need to be reformed to encourage farmers adapt to climate change and to promote particular adaptation methods. With regard to education, it is important for the Tanzanian government to make sure that young household members are provided with suitable education so that they are able to provide relevant advice to their elders about modern and appropriate adaptation approaches. Thirty six percent and 55 percent of farmers located in the arid and semi-arid agro-ecological zones respectively reported shortage of water for irrigation as a major constraint to adaptation. In this case the government should encourage the farmers to concentrate on farming drought resistant crops instead of planting crops that require more water while at the same time developing irrigation infrastructure in areas where water is available.

The smallholder farmers identified lack of funds, shortage of water for irrigation, poor planning, and shortage of the seeds recommended by agricultural experts as the main constraints in undertaking adaptation. In the case of lack of funds, the Tanzanian government should aid the farmers that are not yet in SACOS and/or VICOBA to form groups so that they can be considered for low-interest agricultural loans. To diminish the problem of seed shortage, the government should ensure agricultural officers and agents provide the appropriate amount of required subsidized seeds at the appropriate time. As for poor planning, farmers should be enabled to consider suitable and appropriate activities given the climate condition; that is, they should be supported to develop long term adaptation plans even if this means switching crops completely or engaging in activities other than agriculture.

Furthermore, on the basis of the results on key drivers of specific adaptation methods revealed in this study, the government can play a significant role by promoting adaptation methods appropriate for particular circumstances e.g. particular crops or agro-ecological zones. The results also contribute guidance for targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods. For example, the probability of farmers in the arid agro-ecological zone using short season crops, and irrigation as their adaptation strategies is very low. Thus in these cases, the government can promote the use of drought resistant crops because they do not require plentiful water. In the Coastal agro-ecological zone (Tanga administrative region) farmers are most likely to grow short season crops. This is one of bimodal areas, that is, the regions that receive two rainy seasons namely; a long rainfall season (Masika; March to May) and a short rainfall season (Vuli; October to December). During the Vuli rainfall season, farmers in Tanga are reported to grow composite maize which does not require long period and plentiful rain to mature (USDA, 2003). In this case, therefore, the government is advised to invest in research and development (R&D) for short season crop varieties.

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Appendix 4.1: Results for farmers' choice of adaptation methods

Table 4.6: Heckman Sample selection model

	Outcome equation: Choice of adaptation method					**Selection equation: Probability to adapt**
Explanatory variable	**Method 1** Short season crops	**Method 2** Crops resistant to drought	**Method 3** Irrigation	**Method 4** Changing planting dates	**Method 5** Planting trees	
Annual household income	-0.047 (0.234)	0.269 (0.245)	0.229 (0.336)	- 0.024 (0.28)	0.133 (0.409)	0.204 (0.149)
Number of years worked as farmer	0.001 (0.007)	-0.011 (0.008)	-0.01 (0.014)	0.007 (0.009)	0.006 (0.01)	-0.002 (0.005)
Farm size	0.131 (0.133)	-0.017 (0.127)	-0.059 (0.161)	-0.083 (0.144)	-0.464** (0.202)	-0.109 (0.079)
Highest education in the household	-0.02 (0.041)	0.091** (0.043)	0.081 (0.061)	- 0.141*** (0.048)	0.131** (0.063)	0.061*** (0.023)
Size of the household	0.001 (0.03)	-0.005 (0.029)	-0.025 (0.039)	0.012 (0.035)	0.022 (0.041)	0.001 (0.018)
Average temperature in the neighbourhood in 2010	0.248*** (0.071)	0.167* (0.089)	-0.06 (0.101)	-0.063 (0.079)	-0.337** (0.154)	-0.153*** (0.056)
Average rainfall in the neighbourhood in 2010	-0.0001 (0.001)	0.001 (0.0008)	0.004*** (0.001)	-0.002 (0.001)	-0.003 (0.003)	-0.002*** (0.001)
Head of household is male#	-0.089 (0.233)	0.097 (0.239)	-0.131 (0.289)	-0.213 (0.267)	0.386** (0.306)	0.114 (0.139)
Household has access to media#	0.097 (0.238)	0.077 (0.234)	0.289 (0.313)	0.466* (0.276)	0.368 (0.334)	0.165 (0.143)

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Access to credit#	0.099 (0.226)	0.143 (0.233)	- 0.059 (0.271)	-0.74*** (0.26)	0.641** (0.281)	0.106 (0.138)
Frequency experienced drought in the past 20 years#	0.012 (0.058)	0.081 (0.063)	0.051 (0.074)	-0.19** (0.083)	0.207* (0.107)	0.083** (0.032)
Frequency experienced flood in the past 20 years#	-0.076 (0.086)	-0.082 (0.098)	0.078 (0.11)	0.158* (0.091)	-0.129 (0.117)	-0.041 (0.052)
Has received technical support#	0.343 (0.233)	-0.015 (0.231)	-0.259 (0.322)	-0.146 (0.275)	-0.006 (0.312)	0.042 (0.143)
Grows rice as the major crop#	-1.332* (0.69)	0.258 (0.701)	-0.634 (0.95)	0.983 (0.872)	-2.899** (1.232)	1.313*** (0.50)
Grows sorghum as the major crop#	0.055 (0.472)	0.015 (0.357)	2.061** (0.935)	-0.055 (0.435)	0.288 (0.485)	0.106 (0.251)
Located in the Coastal agro-ecological zone#	0.07** (0.026)	-0.049 (0.031)	-0.006 (0.037)	-0.019 (0.032)	-0.106** (0.048)	2.233*** (0.583)
Located in the Plateau agro-ecological zone#	0.113 (0.447)	-0.07 (0.414)	1.345** (0.667)	0.599 (0.54)	1.664 (1.053)	1.074** (0.429)
Located in the Alluvial plains agro-ecological zone#	0.409 (0.473)	-0.894** (0.425)	3.091*** (0.818)	0.125 (0.441)	0.487 (0.572)	-0.075 (0.258)
Located in the Southern highlands agro-ecological zone#	0.566 (0.561)	-1.466** (0.661)	2.947*** (0.921)	-0.502 (0.565)	1.337** (0.601)	-0.007 (0.319)
Located in the Semi-arid agro-ecological zone#	1.056** (0.623)	-0.375 (0.624)	2.556*** (0.929)	-0.749 (0.787)	0.211 (0.688)	-0.023 (0.373)

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Distance from input markets						-0.036* (0.019)
Has observed changes in rainfall and temperature#						1.174** (0.586)
Constant	-4.898 (3.697)	-1.414 (4.209)	-8.473 (5.318)	8.226* (4.028)	3.714 (5.961)	1.099 (2.43)
Inverse Mill's Ratio	**-2.889*** (0.75)**	**-0.064 (0.693)**	**-0.709 (1.12)**	**-5.329*** (0.935)**	**-1.937 (1.644)**	
Number of Observations (543)	**131**	**93**	**31**	**60**	**37**	**534**
Log Likelihood	**-715.63154**					**-323.59193**
Wald chi2 (p-value)	**440.46 (0.0000)**					**45.96 (0.002)**

Note:

- *Base category for adaptation methods is "No adaptation"*
- *Base category for agro-ecological zone is Arid*
- *Standard errors are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*

Table 4.7: Marginal effects Heckman Sample selection model using MNL as outcome equation

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
Explanatory variable	**Method 1** **Short season crops**	**Method 2** **Crops resistant to drought**	**Method 3** **Irrigation**	**Method 4** **Changing planting dates**	**Method 5** **Planting trees**	
Annual household income	0.035 (0.057)	0.027 (0.05)	0.003 (0.004)	-0.035 (0.037)	-0.001 (0.001)	0.061 (0.052)
Number of years worked as farmer	0.001 (0.002)	-0.002 (0.002)	-0.0002 (0.0002)	0.001 (0.001)	0.00002 (0.0002)	-0.001 (0.002)
Farm size	0.009 (0.033)	0.016 (0.025)	-0.001 (0.002)	-0.009 (0.018)	-0.001 (0.0004)	-0.034 (0.028)
Highest education in the household	0.009 (0.012)	0.012 (0.01)	0.001 (0.001)	-0.02** (0.008)	0.0001 (0.002)	0.023*** (0.008)
Size of the household	-0.001 (0.008)	-0.003 (0.006)	-0.0003 (0.001)	0.003 (0.004)	0.0001 (0.001)	0.0001 (0.006)
Average temperature in the neighbourhood in 2010	0.018 (0.026)	-0.006 (0.028)	-0.001 (0.002)	-0.03 (0.017)	-0.0001 (0.0004)	-0.056*** (0.02)
Average rainfall in the neighbourhood in 2010	-0.001** (0.0003)	0.001** (0.0003)	0.0001** (0.00003)	-0.0002 (0.0003)	2.33e-06 (0.0001)	-0.001*** (0.0003)
Head of household is male#	0.035 (0.054)	-0.004 (0.048)	-0.002 (0.005)	-0.023 (0.035)	0.0003 (0.001)	0.042 (0.051)
Household has access to media#	0.081	-0.013	0.003	-0.077	0.0001	0.054

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
	(0.05)	(0.048)	(0.004)	(0.049)	(0.001)	(0.053)
Access to credit#	0.064 (0.056)	0.024 (0.044)	-0.001 (0.004)	-0.099*** (0.032)	0.001* (0.001)	0.049 (0.049)
Frequency experienced drought in the past 20 years#	0.023 (0.015)	0.006 (0.013)	0.001 (0.001)	-0.026** (0.011)	0.0001 (0.0002)	0.030*** (0.012)
Frequency experienced flood in the past 20 years#	-0.036* (0.019)	-0.002 (0.019)	0.002 (0.001)	0.022** (0.01)	-0.0001 (0.0002)	-0.016 (0.019)
Has received technical support#	0.111** (0.052)	-0.039 (0.046)	-0.006 (0.005)	-0.027 (0.032)	-0.0004 (0.001)	0.015 (0.052)
Grows rice as the major crop#	-0.041 (0.239)	-0.142** (0.072)	-0.006 (0.007)	0.113 (0.275)	0.001 (0.006)	0.307*** (0.062)
Grows sorghum as the major crop#	-0.243*** (0.033)	-0.179*** (0.025)	0.999*** (0.001)	-0.092*** (0.018)	-0.001*** (0.0003)	0.075 (0.081)
Located in the Coastal agro-ecological zone#	0.0002 (0.157)	-0.34*** (0.113)	0.914*** (0.159)	-0.098 (0.064)	-0.091 (0.09)	0.555*** (0.079)
Located in the Plateau agro-ecological zone#	-0.219*** (0.028)	-0.203*** (0.027)	0.996*** (0.187)	-0.087*** (0.017)	-0.001*** (0.0003)	0.298*** (0.06)
Located in the Alluvial plains agro-ecological zone#	-0.188*** (0.04)	-0.249*** (0.036)	0.999*** (0.038)	-0.088*** (0.02)	-0.001*** (0.0004)	0.011 (0.09)
Located in the Southern highlands agro-ecological zone#	-0.229*** (0.028)	-0.205*** (0.024)	0.997*** (0.121)	-0.091*** (0.017)	-0.001*** (0.0004)	0.026 (0.11)
Located in the Semi-arid agro-ecological zone#	-0.216***	-0.193***	0.998***	-0.099***	-0.001***	0.05

	Outcome equation: Choice of adaptation method					Selection equation: Probability to adapt
	(0.03)	(0.027)	(0.118)	(0.019)	(0.0004)	(0.126)
Distance from input markets						-0.012* (0.007)
Has observed changes in rainfall and temperature#						0.43** (0.184)
Inverse Mill's Ratio	**-0.012** **(0.229)**	**-0.073** **(0.202)**	**0.002** **(0.019)**	**-0.558**** **(0.198)**	**-0.002** **(0.005)**	
Number of Observations (556)	**131**	**93**	**31**	**60**	**37**	**534**
Base rate	**0.25298**	**0.1763**	**0.0089**	**0.0863**	**0.0013**	**0.6685295**

Note:

- *Base category for adaptation methods is "No adaptation"*
- *Base category for agro-ecological zone is Arid*
- *Standard errors are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

Table 4.8: Hausman test for Independence of Irrelevant Alternatives (IIA)[53]

Omitted	Chi-square	Prob (Chi-square)	Evidence
Plant short season crops	0.07	1.0000	For Ho
Plant crops which are resistant to drought	0.68	0.9985	For Ho
Irrigation	0.62	1.0000	For Ho
Change planting dates	1.20	0.9771	For Ho
Plant trees	0.87	0.8217	For Ho

[53]The Hausman test was conducted to determine whether one of the key assumptions underlying the multinomial logit specification is fulfilled (that is, the assumption of Independence of Irrelevant Alternatives (IIA)). The assumption holds when, under the null hypothesis, there is no misspecification of the estimation. The results in this table show that the IIA assumption holds in all categories (that is the H_0 that there is IIA is not rejected).

Chapter 5: Economic Incentives for Climate Change Mitigation: An Analysis of Factors Affecting Household Willingness to Participate in the REDD+ program

Abstract

Tanzania has been listed as one of the countries with high rates of deforestation and forest degradation. Reducing deforestation and forest degradation is an important strategy for reducing greenhouse gas emissions. However, asking households to reduce deforestation means asking them to sacrifice important direct benefits they get from forest products such as daily energy resources. The REDD+ program provides a way in which to compensate households. This study estimates the willingness of households to accept forest use restrictions governing participation in the REDD+ programme and its determinants. The results show that households will participate in REDD+ if the programme can compensate them with an average of TZS 3.3 million (USD 2072) per year. The determinants of willingness to participate are analysed using the Heckman sample selection model. The results reveal that awareness about REDD+ economic incentives, awareness that deforestation and forest degradation is not good for the environment, and increase in time used to collect the most important forest products increase the households' probability of participation in the programme. Households that earn more from forest products demand more financial incentive to participate. The results further reveal that, once the household that is aware of the programme and its incentives decides to participate in the programme they tend to demand less compensation. In this case, the Government of Tanzania is advised to (i) collect baseline data in order to differentiate incentives for households depending on their forest reliance, (ii) educate people about the relationship between REDD+ and climate change to increase the cooperation of the communities.

Keywords: *REDD+, carbon dioxide emission, Climate change mitigation, Economic incentives, Heckman's procedure*

5.1 Introduction

Tanzania is cited to be one of the ten countries with the largest forest net loss per year (FAO, 2006). FAO (2006) observed that between 1990 and 2005, the deforestation rate in those countries was roughly 13,000,000 hectares per year. For developing countries like Tanzania, deforestation and forest degradation are most likely to increase in the absence of pro-conservation interventions. This is due to sustained population growth, continued reliance on fuelwood for domestic heating, and inevitable future economic demands requiring land clearing for agricultural activities.

Forty five (45) percent of terrestrial carbon is stored in forests; and at the same time, deforestation contributes to carbon dioxide (CO_2) emissions of about 15 to 20 percent (IPCC, 2007). The World Development Report (2010) reveals that between 2000 and 2005, net global deforestation was about 7.3 million hectares which contributed to emissions of about 5.0 gigatons of CO_2 per year. This assumes that CO_2 levels per hectare are 500 – 750 tons (Grieg-Gran, 2006). The loss of natural forests without replacement leads to more emissions than from the transport sector (Stern, 2007). The Intergovernmental Panel on Climate Change (IPCC) estimate that 18 to 20 percent of existing global annual carbon emissions is from the loss of tropical forests (URT, 2009). This makes conserving tropical forests essential in order to arrest climate change.

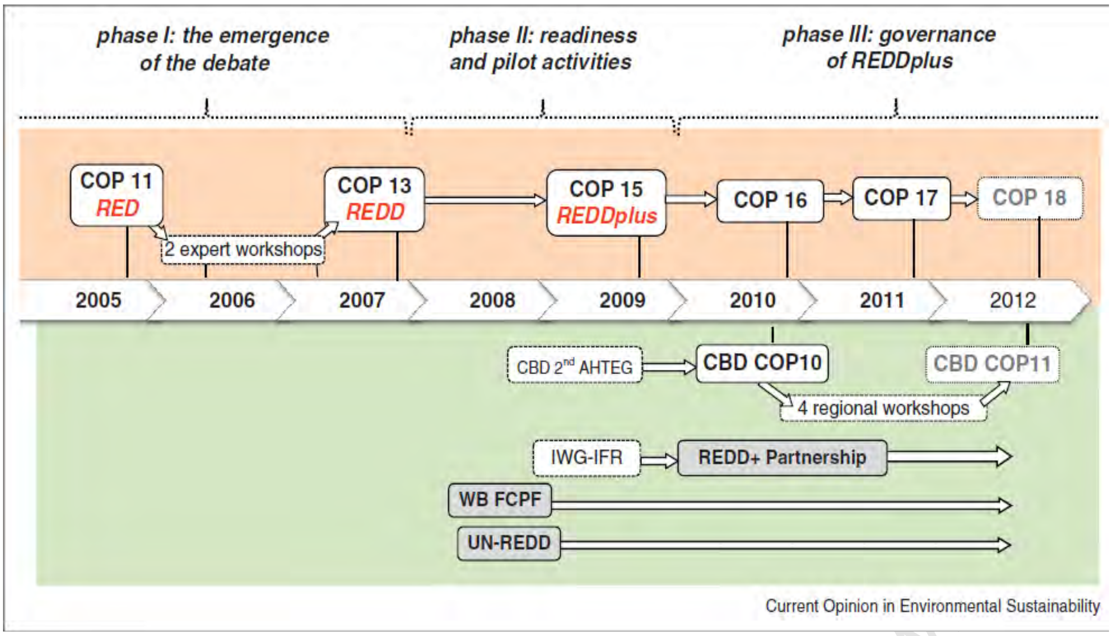
Tanzania is one of the developing countries that are vulnerable to deforestation and forest degradation. Deforestation involves turning forests into other types of land cover while forest degradation entails the loss of ecosystem services caused by different factors (Sasaki & Putz, 2009). Deforestation and forest degradation happen because forest products (mostly timber products) are used in Tanzania as source of energy (charcoal and firewood), for building materials, furniture, and infrastructure such as electricity and telephone poles. A large number of trees are used to produce charcoal which is the main source of energy for medium and low income earners especially in towns and cities.

The project Reducing Emissions from Deforestation and Forest Degradation (REDD+) is designed to mitigate climate change through suitable sets of policies and incentives (Angelsen & Rudel, 2013). Reducing deforestation and forest degradation is key to slowing greenhouse gas emissions (World Development Report, 2010). However, asking households to reduce deforestation in developing countries usually means asking them to sacrifice the important direct benefits they get from forests products. These benefits include the net income that households receive from the sale and consumption of timber products,[54] the benefits of agricultural production,[55] and the benefits of using charcoal and firewood as sources of energy. Thus, there is a need to reduce deforestation while taking into consideration that households should be compensated for the benefits they are foregoing by not cutting down trees. It is expected that the financial compensation they will receive from the programme will be used on alternative energy sources and other raw materials. For example, farmers are expected to use the incentives to buy fertilizers for their existing plots instead of clearing new land for agriculture.

The launch of the programme for REDD+ by the UN is important since it seeks to lower emissions by paying countries for reducing deforestation and forest degradation. As shown in figure 5.1, REDD+ emerged as a UN initiative that aims at creating incentives for developing countries to protect and manage existing forests efficiently in order to contribute to the worlds' fight against climate change. The initiative started with the launch of the programme on Reducing Emissions from Deforestation (RED) at the eleventh Conference of the Parties (COP 11) in 2005 where the main focus was support for activities that contribute to reducing greenhouse gas emissions from deforestation. Scientists argued that a major weakness in the RED programme was the exclusion of forest degradation which is also a major contributor to emissions (Pistorius, 2012). Thus at COP 13 (2007), the United Nations Framework Convention on Climate Change (UNFCCC) proposed including forest degradation in the programme (REDD). Some countries like India and China were hesitant with regard to reducing emissions from deforestation and forest degradation (Pistorius, 2012). In order for them to contribute to climate change mitigation, the programme decided to widen its ambit. According to UNFCCC (2010) REDD+ includes conservation, sustainable management of forests and enhancement of forest carbon stocks as strategies as well as those covered by REDD. REDD+ is the main focus of this study.

[54] In Tanzania, timber products include wood (for electricity and telephone poles, furniture, building materials); charcoal and firewood.

[55] Since most forests are convertible to arable land, reducing deforestation means restricting people from clearing new land for agricultural activities.



Source: *Adopted from Pistorius (2012)*

Figure 5.1: From RED to REDD+

REDD+ focuses on reducing deforestation and forest degradation, enhancing and conserving forest carbon stocks, and sustainable management of forests (Herold and Skutsch, 2011). It offers an important role for forest conservation in reducing the negative impact of climate change (Burgess et al., 2010). REDD+ is not only about compensating households for conserving trees but also incentivising sustainable forest management.

In 2009, Tanzania launched the national REDD+ initiative aimed at reducing CO_2 emissions. The UN-REDD program paid Tanzania the sum of USD 4.2 million as a REDD+ Quick-Start Initiative (UN-REDD Programme, 2009). The government is already developing a National Strategy and Action Plan for REDD+ to be facilitated through a Forest Resources Task Force as a way of envisaging participating in the future REDD+ policy and in its development (URT, 2009). Various NGOs have been interacting with forest stakeholders within the country with the aim of raising awareness of REDD+ initiatives and asking for important information in order to develop the national REDD+ strategy. Tanzania is also receiving a donation of the sum of about USD 80 million from the Norwegian government to support national REDD+ strategy development (Burgess et al. 2010). This amount is given to different groups in Tanzania to motivate them to support different REDD+ projects and protect Tanzanian forests.

The greatest concern for REDD+ is to craft the appropriate incentives for forest users to stop cutting trees. REDD+ should also consider how such incentives are channelled to forest users.

It is without a doubt that REDD+ payments should be made to the major forest users or forest owners aiming to compensate them directly for the carbon benefits that well conserved forests provide. Given that global REDD+ programme payments are only made to national authorities, the government should establish the appropriate mechanism to compensate the households who manage the forests. To contribute towards this goal, this study investigates the incentive mechanisms needed to successfully implement a national REDD+ programme in Tanzania. This is accomplished by means of (i) identifying the groups that threaten forests within and outside households, (ii) investigating the values that agents derive from deforestation and forest degradation, (iii) examining the extent to which households can willingly participate in REDD+, and (iv) assessing the appropriate incentive mechanisms that Tanzania can craft to motivate households to participate in REDD+.

The rest of the chapter is organized as follows: Section 5.2 presents a brief review of the relevant literature. Section 5.3 describes the study area, survey instrument and data, and provides descriptive statistics. Sections 5.4 and 5.5 outline the main economic and econometric models employed. Section 5.6 analyses results; and lastly, section 5.7 concludes and draws policy implications.

5.2 Literature review

Numerous studies on efforts to address climate change have pointed out that the focus should be on mitigation (see for example, Kandlikar & Sagar, 1999; Kates, 2000; Lorenzoni et al., 2000; Sharma & Kumar, 1998). Since it is believed that one fifth of global greenhouse gases come from deforestation and forest degradation (IPPC, 2007), it is important to focus on mitigating climate change through better forest management. This is more relevant now that developed countries are considering financially supporting developing countries through various projects like REDD+. In this context the concept is that, developed countries help developing countries to reduce national deforestation rates voluntarily by providing financial incentives. That is, countries that show emissions reductions can sell the carbon credits in the international carbon market (Gibbs et al, 2007). Among other activities, Decision 4/COP15 states that developing countries should identify drivers of deforestation and forest degradation as well as the activities within the country that result in reduced emissions and increased removals and stabilisation of forest carbon stocks (UNFCCC, 2010). It is known that, tropical forests store more carbon per unit area than non-tropical forests (Davis, 2008).

In light of the significant number of livelihoods which are going to forego current benefits by the imposition of restrictions on forest use, REDD+ emphasises the provision of financial incentives to stop Tanzanians felling trees by selling carbon credits[56] (Sam, 2010). However, the main question is the amount of compensation households require for them to stop deforestation and forest degradation and manage forests sustainably. Designing effective REDD+ financial incentives is difficult because REDD+ deals with the idea of changing household behaviour toward forests. These forests are the resources on which the nearby communities are dependent for their subsistence. According to Miles et al. (2009), 90 percent of the national energy supply and 75 percent of building materials in Tanzania come from Miombo woodlands. In this case, reform in the forestry sector that leads to restricting households from forest use is going to impact on the majority of the households, especially those with low and middle income. Viana et al. (2012), in analysing the role of community forestry in REDD+, argue that forest communities have an important role to play in achieving the goals of REDD+.

REDD+ seems to be an effective way of achieving green-house gas (GHG) reductions because it is cost-efficient as it does not entail application and/or creation of costly technologies. It also appears that REDD+ is equitable in that it allows the inclusion of developing countries in global mitigation efforts. Developing countries will not only gain the benefit of preserving their forests but also the forest communities will have the opportunity of alleviating their poverty through the financial incentives provided by REDD+ (Angelsen, 2009). Studies that support the pro-poor approach argue that REDD+ should be designed in such a way that it adds substantially to decreasing the poverty of forest dependent communities and does not do any harm to the poor (Campbell, 2009; Seymour, 2008). The argument of poverty alleviation using REDD+ as a type of PES (Payment for Environmental Services) scheme is opposed by other studies which insist that payments should be made based on environmental services and not on poverty levels. (Wunder, 2008).

The designing of appropriate financial incentives for REDD+ will have the advantage of reducing the amount of carbon emissions and helping local forest users reduce their poverty through the financial incentives provided by the programme (Dewees et al., 2010). If REDD+ develops attractive incentives, it will be easy to convince households to stop deforestation as forestry activities will not be as necessary for their well-being (Overdevest & Green, 1995).

[56] Carbon credits is a measure of the change in carbon stocks

Burgess et al. (2010) suggest that in order for REDD+ to be successful, the current users of forest products must implement other practices and an equitable sharing of REDD+ benefits amongst all households in the community. Burgess' (2010) suggestion about sharing REDD+ benefits only seems reasonable where there is homogeneity of use of the forest in the community. With heterogeneity of use, there will be no incentive for the main users to stop deforestation if the REDD+ benefits will be equally shared among households. Thus, sharing of REDD+ benefits should be fair. That is, households that currently earn more from forest products should be better compensated. The important thing that Burgess and others did not look at was whether households are willing to participate in the programme. This study is therefore contributing to the literature by filling this information gap. The study analyses the willingness of Tanzanian households to participate in REDD+ and the minimum amount that they are willing to accept for their participation. As Busch (2013) argues, it is the responsibility of developing countries to design their own policies to achieve forest carbon emission reductions. Thus the results of this study provide recommendations to the Tanzanian government on effective policies for incentives that will motivate households to participate in the mitigation process.

5.3 Description of Variables and Data Sources

The survey was conducted in seven administrative regions in Tanzania (Coast, Tanga, Dodoma, Morogoro, Iringa, Lindi, Shinyanga) and includes 1034 households. The regions were purposely selected because of the existing massive deforestation and forest degradation in the area and because REDD+ has already been launched in two of the surveyed districts. The households that participated in the sample, however, were randomly selected and the sample includes both households who are participating in REDD+ activities and those who are not.[57] The random sampling method allows for an equal chance of inclusion in the sample for every household in area of the study. Participation was voluntary and ethical considerations were taken into account with households being assured of the confidentiality of the information they provided to the researcher. The intention of this study is to determine households' willingness to accept financial compensation to participate in the REDD+ programme. Household members were visited and interviewed at home. Although they are very expensive to undertake, personal interviews are generally believed to produce greater willingness to accept (WTA) data.

[57] The information on the participation process is provided in the questionnaire presented in the appendix 5.2

The questionnaire (see Appendix 5.2) consists of three main parts. The first part investigates the socio-economic dynamics of the households targeted for the study. This is important because it provides the characteristics of the households that are willing to participate in the programme. The second part covers deforestation and forest degradation. The aim of this section is to understand the rate of deforestation and forest degradation in general, the groups that are involved in deforestation and degradation, the causes of deforestation and degradation, and the types of forests that are affected by these activities. The respondents were all forest users though their scale of usage differed. Some use the forests for domestic uses (new land for agriculture, fuelwood, timber for house construction) and some use the forest for commercial purposes.

The last section of the questionnaire is concerned with climate change and the REDD+ programme. There is a brief introduction as to what is offered by REDD+ and its expectations from households that are willing to participate. The respondents were first asked if they were aware of the REDD+ programme and the economic incentives it provided. They were then asked if they are willing to participate in the programme. This means they were asked if they are willing to comply with all the usage restrictions which will be imposed by the programme. Respondents who showed willingness to participate were asked to give the minimum amount (in Tanzanian shillings) that the household would be willing to accept as compensation for them to stop cutting trees for any use they mentioned. We are aware that open ended questions usually create biases but we sought to minimise this by reminding the respondents that they had told us the value of the forest products they were currently extracting. In this case we expected the respondents to anchor their open ended responses to their current forest income. To prove the expectations we had to the respondents, the study measured the strength and direction of a linear relationship between the income that households derive from deforestation and the minimum amount they are willing to accept to participate in the programme. The correlation coefficient (0.4918) indicates that the amount that the household is willing to accept to participate in the programme increases as the income derived from deforestation increases. The low amount obtained from forest products is largely caused by the low price of forest products in the forest areas where the respondents live. But the amount of forest they destroy contributes significantly to deforestation and forest degradation and hence REDD+. The statistics of the variables used in the study are explained below and presented in table 5.1.

Variables included in regressions

After being asked about their awareness of REDD+, the respondents were asked about their willingness to participate in the programme. For this study, the term willingness to participate in REDD+ means that a household is willing to stop deforestation and forest degradation mainly by ceasing to cut trees in forests for any purpose. This approach is used by economists who want to study the value of non-market goods. To determine the households' willingness to participate and the minimum payments they are willing to accept, the study uses the approach commonly known as Contingent Valuation (CV). Data on the loss of the benefits/welfare as a result of the discontinuation of tree cutting is not generally available. However, it can be established by considering the household's expenditure function. Normally, an expenditure function is the function of prices and maximised utility levels $e(p,U_0)$. Prices need to change (increase or decrease) in order for a consumer to reach a given utility level. But in this case, where there is no market for forest resources, a change in quantities of nonmarket forest resources is used to measure the welfare alteration of forest users. Freeman (1993:72) points out that it is important that quantities of some environmental goods are available in the same amount. Thus, restrictions in the availability of those resources act as constraints on the choice of the resource user's consumption bundle.

The dependent variables include an indicator variable and a level variable for willingness to participate in the REDD+ programme. If the household responded that they were willing to participate in the programme, the indicator variable for willingness to participate takes the value one, otherwise it takes the value zero. Among all 1034 respondents, 958 (accounting for 93 percent) responded that they were willing to participate in the programme. These households were then asked to mention the minimum amount that they were willing to accept to participate. This causes sample selection bias (Heckman, 1979) and therefore there is a need for this study to use Heckman sample selection model to check for selection bias.

Compensation for stopping deforestation is the amount of payment that is expected to be accepted by the household willing to participate in REDD+.[58] This amount is expected to be at least equal to the benefits that a household is going to forego for participating in the programme. The households had to state a desired amount as opposed to accepting or rejecting a proposed amount; (this comes from an open-ended question). The households

[58] In our regression, the minimum amounts that the household is willing to accept to participate in the programme are in natural log-scale in order to reduce the skewness of the dependent variable.

indicated that they would participate in REDD+ if the programme could compensate them with a minimum of 3.3 million Tanzanian Shillings (which is equivalent to USD 2072) on average. This is higher than the median of 2 million Tanzanian shillings. The statistics indicate that the amount they require to participate in the programme is 426 percent more than their current forest income. This is expected since we know from the endowment effect hypothesis that people tend to assign more value to things they own than to what they obtain. In this case, willingness to accept compensation tends to be greater than willingness to pay for it (Kahneman, et al. 1990; Carmon & Ariely, 2000; Hossain & List, 2010). A marked willingness to accept figures can also be supported by Prospects Theory as proposed by Daniel Kahneman (Kahneman & Tversky, 1979). This theory argues that individuals value gains and losses differently. In fact the theory justifies the concept that losses hurt more than the gains please. In cases like this when individuals are uncertain about REDD+ payments, that is, the probability of receiving compensation is small, and there is a tendency to overweight the payments (McDermott, et al., 2008). Households around forests are attached to the forest products they harvest. Asking them to stop cutting trees means they are going to lose the amount they have been acquiring from forest products. It is expected that they will be willing to stop cutting trees if they are compensated more substantially. Thaler (1980) also finds that people tend to value highly the things they own because they feel giving them up as a loss. In this case, they tend to ask greater compensation to cover their loss.

Household specific factors here include the age, marital status and gender of the head of household, size of the household, number of children still at school, education of the head of the household and the highest education level of members in the household, as well as awareness about the effect of deforestation and forest degradation. These factors are very important in order to determine the possibility of the household ceasing deforestation. For example, if a household is aware of the effect of deforestation and forest degradation, the possibility of their participation in the REDD+ programme is expected to increase.

The age of household heads ranged between 20 and 90 years with an average of 46 years. On average, household heads have 6 years of education, the years counted from the year they began primary school. In Tanzania, primary school education takes 7 years. This means that on average, household heads have not completed their primary school education. 75 percent of households are headed by men and 80 percent of household heads are married. On average, households have 7 members and 2 school-going members.

The household's income derived from forest use includes all incomes that the household derives from consuming and the selling (if any) of agricultural products from newly cleared land, income from charcoal, firewood, and timber products. This variable is included in the regression to see how much the household is willing to sacrifice when it decides to participate in REDD+. The average income from forest use is 0.77 million Tanzania Shillings which accounts for 86 percent of the households' total income.

There are other important variables for this study. These include the most important forest products, the availability of these products and the groups that are the main forest users. Other important variables are household awareness that deforestation and forest degradation is not good for the environment, whether the community is targeted for REDD+ rollout, and household awareness about REDD+ financial incentives.

On average, 78 percent of households are aware that deforestation and forest degradation is not good for the environment. In our sample, 59 percent of households are aware of REDD+ economic incentives, and 33 percent of respondents reported that their communities are targeted for REDD+ rollout.[59] It should be noted here that there are more respondents who are aware of REDD+ and its financial incentives than those that reside in the communities that are actually targeted. This is because many communities receive information about REDD+ through media as well as from relatives coming from those communities that are targeted for REDD+ rollout. Eighty nine (89) percent said that the time that the household uses to collect the most important forest products has increased compared to previous years.

Table 5.1: Descriptive statistics of the variables included in the regression

Variable	Observations	Mean	Standard deviation	Min	Max
Household's willingness to participate in REDD+ (Yes=1, No=0)	1034	0.93	0.26	0	1
Minimum amount household willing to accept participation in REDD+ ('000 TZS)	958	3,274	3,401	35	22,600
Age of head of the household (years)	1034	45.85	11.98	20	90
Years of education of head of the household	1034	5.7	3.34	0	17
Highest years of education in the household	1034	8.6	2.82	0	18
Head of the household is male (Male=1, female=0)	1034	0.75	0.43	0	1

[59] Those respondents are from some districts in Lindi and Shinyanga regions where the REDD+ programme has been launched

Variable	Observations	Mean	Standard deviation	Min	Max
Size of the household (numbers)	1034	6.5	2.54	1	17
Members of household still at school (numbers)	1034	2.1	1.43	0	8
Head of the household is married (married=1, otherwise=0)	1034	0.8	0.39	0	1
Number of years stayed in the village	1034	30.3	15.31	1	90
Household total income ('000 TZS)	1034	894.78	100.59	18	7,150
Total income from forest use ('000 TZS)	1034	767	968	9	6,825
Household is aware that deforestation and forest degradation is not good for environment (Yes=1, No=0)	1034	0.78	0.42	0	1
The community is targeted for REDD+ rollout (Yes=1, No=0)	1034	0.33	0.47	0	1
Household is aware about REDD+ financial incentives (Yes=1, No=0)	1034	0.59	0.49	0	1
Time used to collect MIP has increased (Yes=1, No=0)	1034	0.71	0.45	0	1
The main forest user is respondent and their household (Yes=1, No=0)	1034	0.24	0.43	0	1

Note: *Mean and Median minimum amount the household is willing to accept to participate into the program are TZS 3,274,011 and TZS 2,000,000 respectively*

5.4 Conceptual Framework

An increase in deforestation and forest degradation leads to a corresponding increase in emissions of greenhouse gases. Data collected for this study show that households are easily capable of mitigating greenhouse gas emissions by better management of the existing forests. However, they have shown clearly that they need to be incentivised to do so. Thus, if they are sure of receiving positive economic incentives, they will change their behaviour towards forests.

REDD+ provides developing countries with financial incentives to stop felling trees by selling their carbon credits to developed countries. For communities, this participation in REDD+ largely means foregoing the positive benefits derived from tree cutting. The payments to developing countries provide opportunities for households to be compensated for the sacrifice they make by discontinuing deforestation and forest degradation. This concept is commonly known as Compensation Variation (see Varian, 1990). It measures how much extra income a household would need to maintain its pre-REDD+ utility. However, it is clear that these households will only participate in REDD+ if the compensation from the programme is greater than the loss from forest use. Assume that before the introduction of REDD+, the household has access to forest resources amounting to Z_0 (e.g. new agricultural land and processed and unprocessed forest products[60]) while with REDD+ the household can only access forest resources amounting to Z_1. Thus, the imposition of forest use restrictions associated with REDD+ potentially causes welfare loss through its impact on production and/or consumption.[61] In this case, therefore, expenditure can be defined as a function of all prices (p) for marketed goods especially non-forest products consumed by the household. These include substitute and complementary products, the maximum utility (U_0) derived by the household from consumption of both forest and non-forest products before the introduction of REDD+, and forest resources accessed before the introduction of REDD+ (Z_0).

$$e(p, U_0, Z_0) ------------------------------ (5.1)$$

Equation (5.1) shows the expenditure or the lowest amount of income needed by the household to obtain the required utility level (U_0) before the introduction of REDD+. The introduction of REDD+ leads to a change in availability of forest resources hence their value shifts from Z_0 to Z_1 where $Z_0 > Z_1$. The shift results in a change in the maximum utility which can be attained by the household. In order for the household to attain the previous utility level in the absence of the initial forest resources, they would have to acquire and thereby spend more on non-forest resources. Thus, a shift from Z_0 to Z_1 results in a change in expenditure or the lowest amount of income required by a household to spend to have the same utility (U_0) as before the introduction of REDD+.

We can measure the monetary value of a welfare change in the household after the introduction of REDD+ by observing the difference in the lowest amount of income required by a household to spend in order to maintain the initial level of utility. Equation (5.2) measures the monetary value of a welfare loss after the introduction of REDD+.[62]

[60] Forest products being the materials/goods obtained from forest resources.

[61] In Tanzania, deforestation is mainly driven by the demand for land in agriculture and fuelwood for household consumption and/or sale. Therefore, restrictions that REDD+ imposes on clearing new agricultural land and obtaining fuelwood reduce the household's access to forests and hence the income that would have been obtained without restrictions.

[62] The welfare change in this case will be the lowest amount of income needed by the household to obtain the required utility level after the introduction of REDD+ minus the minimum amount needed to spend to obtain the same level of utility before the introduction of REDD+.

$$e(p,U_0,Z_1)-e(p,U_0,Z_0)---------------------(5.2)$$

The value of the welfare loss from lost access to forest resources due to the introduction of REDD+ can be established using the Contingent Valuation (CV) Method. In this study, we asked the household the minimum amount of income that they would be willing to accept as compensation for them to comply with a specific set of imposed forest use restrictions (e.g. completely ending tree felling).[63] This minimum amount is assumed to make the household as well off as before complying with the set of forest use restrictions imposed under the REDD+ programme. In this case, the willingness to accept (WTA[64]) for household i can be shown as:

$$WTA_i = e(p,U_{0i},Z_{1i};h_i)-e(p,U_{0i},Z_{0i};h_i)+\varepsilon_{1i}-\varepsilon_{0i}--------(5.3)$$

Equation (5.3) defines the minimum amount that the household will accept to comply with the restrictions and still remain as well of as before the introduction of REDD+, given the household's socio-economic characteristics (h_i). The measurement of household expenditure before and after the introduction of REDD+ is assumed to be effected with a slight error ε_i. In this case, WTA for household i can be specified as a random variable that is a continuous function of some explanatory variables that are reflected in the household's expenditure function. Therefore, equation (5.3) above can be written as

$$WTA_i = X_i\beta+\varphi_i------------------------(5.4)$$

Whereby φ_i is an error term assumed to be normally distributed with zero mean and constant variance and X_i is a vector of independent variables.

5.5 Empirical Framework

This study seeks to (i) identify the forests' main users, (ii) investigate the benefits that households/agents derive from deforestation and forest degradation, (iii) examine the extent to which households can willingly participate in REDD+, and (iv) assess the appropriate incentive mechanisms that Tanzania can craft in order to motivate households to participate in

[63] In fact, in this scenario, the household was initially asked if they are willing to participate in the REDD+ program connected to the forests they normally use and if they will comply fully or partially with a specific set of imposed restrictions. By full compliance we mean that the household is willing to comply with all the forest use restrictions which will be imposed; while partial compliance means that the household would only comply with a few of the imposed restrictions.

[64]WTA is the amount that a person is willing to accept to abandon a good income from forest resources.

REDD+. This section provides an overview of the methodology that will be used to address the objectives of this study.

The first objective is explored through the use of descriptive statistics resulting from a survey asking households to identify the main users of the forests located in their village including themselves. The term *main users* means those who have benefitted the most from forest product subsistence and cash from a given forest type in the past 12 months. They were asked to choose and rank 3 groups among various groups provided.[65] This includes indicating different groups that threaten forests at a community as well as household level.

5.5.1 Heckman Model

Heckman's sample selection model (Heckman, 1979) allows the analysis of a household's decision to participate in the programme, and the magnitude of its participation. An important advantage of the Heckman model is that it controls for sample selection bias that could probably arise because of the existence of unobservable variables that govern the discrete and the continuous choices relating to participation in the programme.

Such biases may emerge from the possibility that households are not randomly assigned. This means, those households that would be willing to accept less or no compensation to participate are the same households that are less likely to participate in the programme. In this case, such households are not included in the subsample used in the estimation of a model of the minimum amount that the household is willing to accept as compensation. In this subsample, the expected value will be biased upward.

The Heckman model considers that observations are ordered into two regimes. In the context of this study, these regimes are defined as whether or not the household is willing to accept a certain amount of income to participate in REDD+ programme. The first stage is known as the selection equation, where the study determines the relationship between the household willingness to participate in REDD+ and different independent variables following the binary

[65] The groups given for the household to choose from were; you and your household; other households in the village; small-scale commercial users in the village; large-scale commercial users in the village; households from outside the village; small-scale commercial users from outside the village; large-scale commercial users from outside the village; and any (specified) others.

probit model. The model uses a binary variable representing the willingness of the household to participate in the programme.[66]

$$w_i = x_i\alpha + \mu_i \text{------------------} (5.5)$$

Where w_i is a binary variable indicating household i's willingness to participate in the programme, x_i are the determinants that lead the household to participate in the programme, α is the vector of parameters to be estimated and μ_i is an error term that follows the standard normal distribution(Gujarati 2003). The likelihood of observing the dependent variable (P $(w_i=1|x)$) is tested as a function of variables including the yields from agricultural activities (obtained from clearing virgin land for farm expansion and from overgrazing), the use of fuelwood (charcoal and firewood), the use of industrial wood (for building materials, furniture, and electricity and telephone poles), household specific factors (e.g. education, age, family size, marital status, gender),[67] as well as household income derived from forest products. Following Woodridge (2001) and assuming that the cumulative distribution of μ_i is normal, a probit model is employed. In this case, the probability that the household will stop cutting down trees and participate in REDD+ is estimated using a probit model specified as:

$$p(w_i = 1 | x) = \Phi(x'\alpha) = \int_{-\infty}^{x'\alpha} \frac{e^{-\frac{(x'\alpha)^2}{2}}}{\sqrt{2\pi}} d(x'\alpha) \text{-----------------} (5.6)$$

Where $\Phi(.)$ is the normally cumulative distribution function, and p is the probability of observing a specific outcome of the dependent variable. The corresponding log likelihood function for the probability is:

$$\ln L = \sum_{i=1}^{n} I_i \ln[\Phi(x'\alpha)] + (1 - I_i)\ln[1 - \Phi(x'\alpha)] \text{------------------} (5.7)$$

This model implies a diminishing magnitude of partial effects for the independent variables and the coefficients give the signs of the partial effects of each of the independent variables on the probability that a household stops deforestation and forest degradation. I_i is a dummy variable equal to 1 if the household is willing to participate in REDD+ and 0 otherwise. The

[66] The variable is a dummy that takes two values, that is, 1 if the household is willing to participate in the programme and 0 otherwise.

[67] Most of the factors derived from deforestation and forest degradation benefit households in one way or another. For the households to participate in REDD+, the programme should provide reservation benefits which should be at least equal to what they get without REDD+ programme.

consistent maximum likelihood parameter estimates are obtained by maximizing the above log likelihood function.

The true effect of compensation from stopping deforestation,[68] households' education, family size, benefits from forest products, and other variables on the probability of whether to stop deforestation can be assessed from the marginal effects formulation. The marginal impact for continuous explanatory variable x_k is given by:

$$\frac{\partial p(w_i = 1 | x)}{\partial x_k} = \frac{\partial \Phi(w_i = 1 | x)}{\partial x_k} = \phi(x'\alpha)\alpha_k \text{------------------} (5.8)$$

Marginal effects for dummy variables are computed as presented in equation 4.4

After the estimation of α using the probit maximum-likelihood method, the second part of the decision process (the outcome equation) involves estimation of an ordinary-least-squares (OLS) regression of the minimum amount that the household is willing to accept for participation, conditional on the set of households who are willing to participate in the programme. That is, for those who have a value equal to 1 in w_i. In order to control for sample selection, the ordinary-least-square regression adds on the Inverse Mills Ratio (IMR)[69] calculated from the linear predictions of the probit model as an additional explanatory variable. The statistical significance of the parameters estimated from the outcome equations is calculated with the Delta method. This method uses a first-order Taylor expansion to create a linear approximation of a non-linear function that can be used to compute the variance and measures of statistical significance (Wooldridge, 2001).

$$E(y_i \setminus w_i = 1, j_i) = j_i\beta + \beta_\lambda \lambda_i \text{---} (5.10)$$

whereby y_i is a dependent variable. This variable is measured as the minimum amount that the household is willing to accept as compensation for participating in the programme; j_i are explanatory variables; β are the coefficients of independent variables that measure the effect of those variables on the compensation from REDD+; and λ_i is the Inverse Mills Ratio.

[68] The term deforestation here represents both deforestation and forest degradation. REDD+ programme deals with co_2 emission but this study uses deforestation to proxy co_2 emission with the assumption that co_2 emissions increase with an increase in deforestation

[69] This is the ratio of the density function of the standard normal distribution, φ, to its cumulative density function, Φ. If this variable is significant, it means that there is sample selection bias in the model (Heckman, 1979).

As with the selection coefficients, care is also required in interpreting the coefficients from the outcome equation, particularly when the variable additionally appears in the selection equation. In this case, the marginal effect as given by Sigelman and Zeng (1999) is:

$$\frac{\partial E(y \setminus w = 1, j)}{\partial j_v} = \beta_v - \alpha_v \beta_\lambda \lambda(\lambda + x\alpha) ------(5.11)$$

To take care of the dummy variables that appear in both equations, the formula suggested by Hoffmann and Kassouf (2005) is adapted. The Inverse Mills Ratio takes on two values corresponding to the dummy variable 1 (where λ_1) and 0 (λ_0), respectively.

$$\frac{\partial E(y \setminus w = 1, j)}{\partial j_v} = \beta_v - \beta_\lambda (\lambda_1 - \lambda_0) ---------(5.12)$$

5.6 Estimation Results

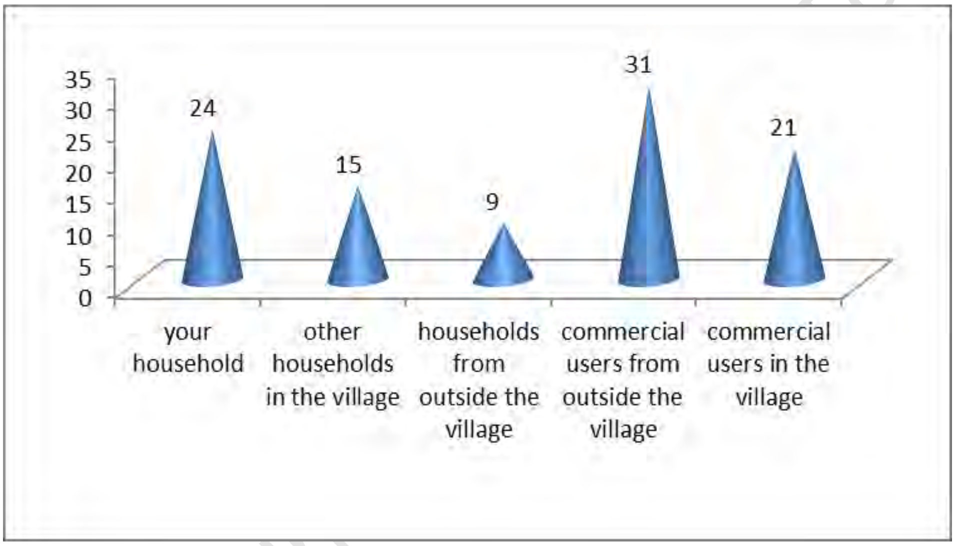
This section provides the estimations used to address the objectives of this study.

5.6.1 Deforestation/ forest degradation and climate change

As the chief interest of this study is to analyse the willingness of the Tanzanian households to participate in the REDD+ programme, the study first investigates the households' awareness of climate change. This might act as a catalyst for the households to want to participate in a mitigation programme. According to the survey conducted in 7 administrative regions with massive deforestation and forest degradation in Tanzania, it is clear that households have observed changes in temperature and rainfall over the past 20 years. In the survey questionnaire, the households were asked to compare present patterns of rainfall and temperature with those of the 1990s. Out of 1034 households who were randomly chosen, 1019 (98.54 percent) observed increases in temperature while 15 (1.46 percent) did not. Similarly, 1018 respondents (98.45 percent) observed decreases in rainfall while 16 (1.55 percent) did not.

Responses around changes in rainfall and temperature reveal that respondents are aware that the climate is changing. The households were further asked if they were aware that deforestation and forest degradation are linked to climate change because they cause CO_2 emissions from trees into the atmosphere. Out of 1034 respondents, 1007 (97.4 percent) were aware of the danger of deforestation and forest degradation to the environment. Although many respondents seemed to be aware of this, the number of the households who had recently cleared forests was high. From the households who were visited during the survey, 402 (39 percent) households admitted that they cleared forest in the past 5 years for different purposes.

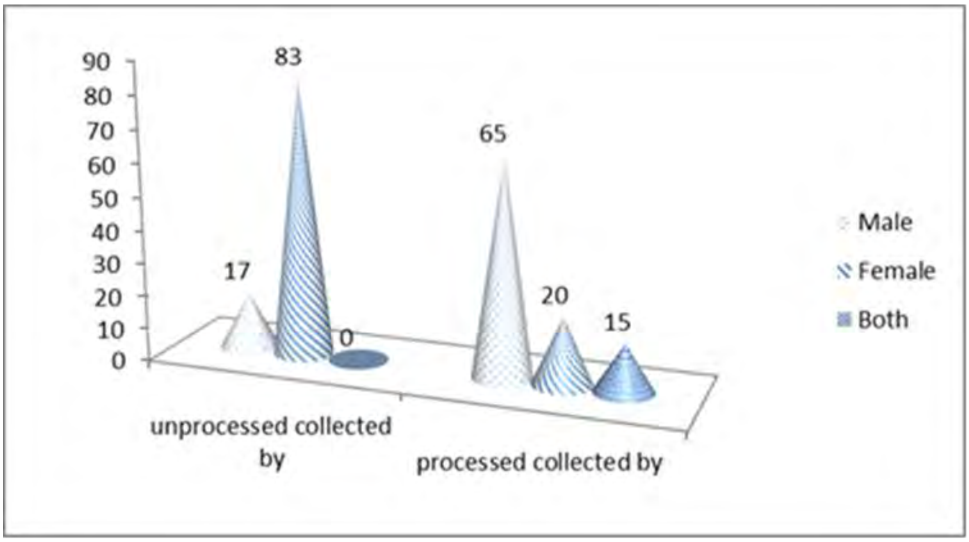
As shown in figure 5.2, the households that admitted to clearing forests are just 24 percent of the main forest users. Thirty one (31) percent of the forest users identified commercial users from outside the village as main users. Fifty two (52) percent of the respondents blamed commercial users within and outside the village. These are companies that harvest timber products for industrial use e.g. building materials and furniture, and households who make charcoal for commercial purposes. Sixty (60) percent of the respondents suggested that locals are more in control of the forest than people from outside the village. Households seem to use forests mainly for subsistence purposes, although some households use the forest for commercial purposes albeit on a very small scale.



Source: Own survey data, October-December 2011

Figure 5.2: Main forest users

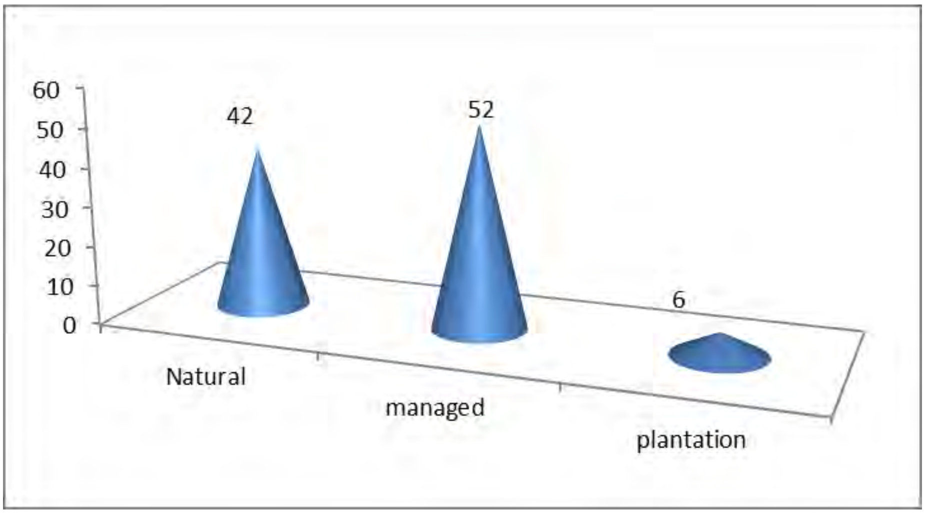
Within the household, men were reported to lead in collecting processed forest products (charcoal and timber for building materials and furniture) while women lead in collecting unprocessed forest products for example; firewood, food/fruits from the bush, forage for their livestock, and plants for medicine. Figure 5.3 shows that, 83 percent of unprocessed forest products within the household is collected by women while men collect 65 percent of total processed forest products.



Source: Own survey data, October-December 2011

Figure 5.3: Main forest users within the household

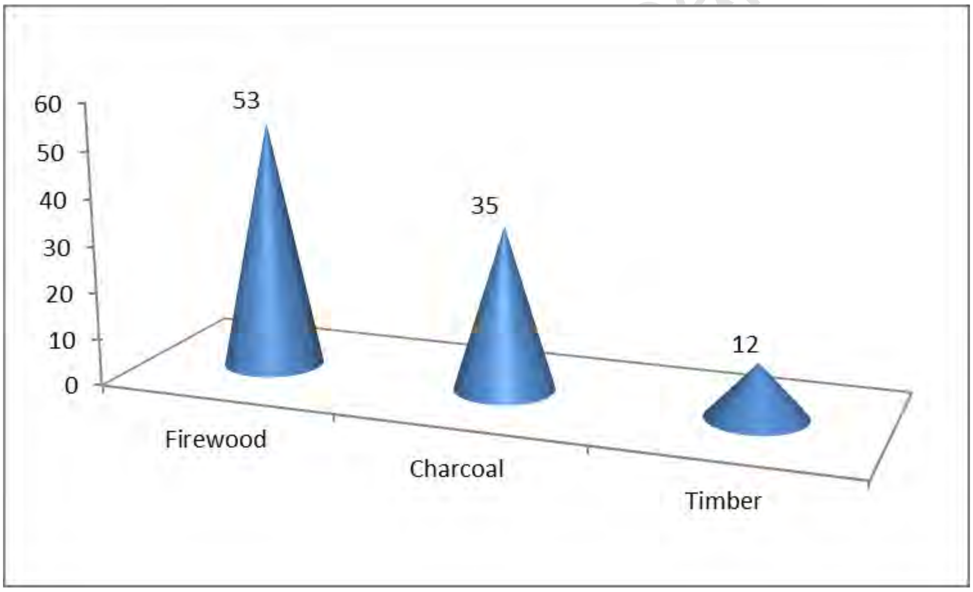
Under normal circumstances it is expected that deforestation should take place more frequently in unmanaged (natural) forests than managed forests. This is not the case in our study. Figure 5.4 reports the finding that 52 percent of the most cleared forests types reported by the respondents are managed forests, followed by natural forests at 42 percent, while only 6 percent are plantations. This can be explained by the fact that in Tanzania protected forests are jointly managed by local communities and the government (TFWG, 2009). This makes it relatively easy for local communities to allow forest users to clear the forests especially when the forest benefit sharing formula does not favour local communities. According to Merger, et al (2012) the REDD+ pilot projects conducted by the Tanzania forest Conservation Group (TFCG) (in Kiswahili Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania (Mjumita)) reported that 16.1 tCO_2/ha and 53.8 tCO_2/ha of carbon stocks are emitted because of unsustainable charcoal production and agriculture (shifting cultivation) in Kilosa (Morogoro) and Lindi sites respectively mainly from natural forests.



Source: Own survey data, October-December 2011

Figure 5.4: Most cleared forest types

As reported in figure 5.5, apart from clearing forests for fertile land for agricultural activities, the most important forest products mentioned by households are firewood, charcoal and timber.



Source: Own survey data, October-December 2011

Figure 5.5: Most important forest products

Now that we have found evidence that Tanzanian households perceive climate change to be occurring in their areas, we will proceed to investigate whether they are willing to participate in the REDD+ programme which this study perceives to be the most effective way to mitigate climate change. This is achieved by investigating the other objectives of the study to find out what will determine the willingness of the households to participate in the programme. First, we perform multicollinearity tests to check whether independent variables in the models to be estimated do not provide redundant information about the response variables. We test for the presence of multicollinearity using the Variance Inflation Factor given by:

$VIFj=1/(1-R^2j)$

where R^2j is the coefficient of determination of the model which includes all independent variables except the jth variable. Table 5.2 below shows that the VIF for all variables is less than 10; hence we can conclude that there is no problem with multicollinearity.

Table 5.2: Multicollinearity diagnosis

Variable	VIF	SQRT VIF	Tolerance	Eigenval	Cond. Index	R-Squared
Age of household head	1.37	1.17	0.736	2.089	1	0.269
Highest education in household	1.14	1.07	0.876	1.651	1.124	0.124
Household head is male	1.4	1.18	0.713	1.575	1.151	0.286
Size of household	1.53	1.24	0.659	1.152	1.346	0.347
Children still at school	1.47	1.21	0.685	1.058	1.404	0.318
Household head is married	1.39	1.18	0.724	0.996	1.448	0.278
Years resident in the village	1.28	1.13	0.779	0.899	1.524	0.221
Awareness that DEF & FD not good for environment	1.07	1.03	0.934	0.868	1.551	0.065
The community is targeted for REDD+ rollout	1.32	1.15	0.759	0.755	1.665	0.241
Awareness about REDD+ incentives	1.28	1.13	0.786	0.562	1.929	0.219
Total household income	1.09	1.05	0.916	0.508	2.028	0.086
Forest main user is your household	1.02	1.01	0.979	0.479	2.097	0.021
Time used to collect MIP increase	1.06	1.03	0.947	0.411	2.257	0.052

Note:

Mean VIF 1.26; Condition Number 2.2573; Determinant of correlation matrix 0.2160

5.6.2 Heckman sample selection model

Table 5.3 presents the results from the Heckman model for willingness to participate and accept compensation from the REDD+ programme. The model has two equations: a selection equation estimating the probability of the household participating in the programme in the forests they normally use, and an outcome equation estimating the minimum amount that the household is willing to accept to participate.

There is a possibility that the Heckman model can be identified when the outcome equation has the same independent variables as the selection equation. The identification occurs due to non-linearity in the selection equation. Non-linearity is introduced into the outcome equation through inverse Mills' ratio. Another restriction of the Heckman model is that different variables might determine participation and outcomes. The independent variables in participation and outcome equations are not exactly the same. The variables are not mutually exclusive; there are some variables that are included in both equations but there are some variables that are not included in the outcome equation. This is because the outcome equation is performed after the participation equation; and therefore, the variables that are necessary in participation equation might not be necessary determinants in the outcome equation because the household is already participating. In this study, the dummy variables for whether your household is a main user of the forest, and the time used to collect the most important forest products are excluded from the outcome equation. It is important to include the variable that captures whether the household is a main user of the forest to determine the household's willingness to participate in the programme. However once the household agrees to participate, the fact that he/she is the main user of the forest does not necessarily determine the minimum amount that the household is willing to accept. The increase in the time used to collect the most important forest products can influence participation in the programme but once the household is already participating the time increase does not matter.

This section analyses the qualitative aspects (coefficient estimates) for the outcome and selection equations (Columns 2 and 4) and then the quantitative effects by calculating the marginal effects following Heckman's procedure as reported by Hoffman and Kassouf (2005). The marginal effects results in the selection equation (column 5) report the marginal effects which are the derivative of the probability of participating in the programme with respect to each variable relative to the average participation of 96 percent (base rate).The marginal effects results in the outcome equation (column 3) report the marginal effects which are a derivative of the minimum amount a household is willing to accept to participate in the programme with respect to each variable relative to the average amount of 14.57 (base rate).

The results show that, the coefficient estimate for the age of the household head is negative and is statistically significant at the 5 percent level. This means as people grow older they are less likely to participate in the programme. The results from the marginal effects in the selection equation suggest that the household head is less willing to participate by about 0.1 percent as age increases. This might be because as the head of the household ages, more responsibility is felt towards family members, and if the household head has been depending on forest products to take care of the family, there will definitely not be a willingness to participate.

The selection equation provides a significantly negative coefficient estimate for the size of the household. Based on the entire sample, findings are that as the size of the household increases the willingness to participate in the programme decreases by 0.5 percent. This is in line with FAO (2001) findings that increases in deforestation and forest degradation (which are the leading cause of CO_2 emission) are partly due to population growth reliance on natural resources, and economic development.

The coefficient estimate of the variable measuring gender of the household head has opposite signs in the selection and outcome equations. The fact that the household head is male decreases the probability of participating in the programme but increase the minimum amount that the household is willing to accept to participate. The marginal effect results show that a male household head decreases the probability of participating in the programme by approximately 4 percent compared to the household with a female head but increases the minimum amount the household is willing to accept. Males that head households call for about 15 Tanzanian shillings more than a female will accept. One of the factors that contribute to this gender difference is dependency on forest products. Within the household, men as opposed to women are shown to be the main users of forest products.

The results show that an increase in the number of years resident in the village increases the probability of participating in the programme but does not have any effect on deciding the minimum amount that the household is willing to accept. Furthermore, the results show that an increase in the household income from forest products increases the minimum amount that the household demands. The marginal effects results show that households are disposed to demand about 0.11 Tanzanian shillings more when their income derived only from forest products increases by 1 Tanzania shilling.[70] This is the household income derived from the sale of forest products that is expected to be sacrificed by the households once they join REDD+.[71] It is demonstrated that household income derived from the sale of forest products

[70] Comparing these results to those in table 5.4 (see appendix 5.1) shows that households increase the minimum to 0.12 Tanzanian shillings more when their level of income derived from forest products as well as from other sources goes up.

[71] The results in table 5.4 (see appendix 5.1) show the effect of the total household income from all sources including from non-forest activities.

increases the minimum amount that the household is willing to accept. That is, the household that earns more from forest products has an incentive to demand more from the programme.

As expected, the dummy variable indicating an increase in the time used to collect the most important forest products (MIP) has a positive effect on the probability of participating in the programme. This means that willingness to accept forgoing forest products increases by almost 10 percent more for households that spend more time collecting forest products. This result is revealing, as it suggests that where the forests' products are not easily available this increases the probability of the household participating in the programme. Surprisingly, there is a negative relationship between being involved in a REDD+ programme rollout and the probability of participating in the programme though the effect is not statistically significant. The negative estimates of REDD+ rollout on the minimum amount the household is willing to accept to participate in the programme is a key contribution of this study. The marginal effects results reveal that households targeted for REDD+ rollout reduce the amount they are willing to accept by roughly 43 Tanzanian shillings. This is surprising but it might be because most of the households in the communities in which the programme has been introduced are aware of the actual incentives. Respondents in the communities that are targeted for REDD+ rollout are dissatisfied with the manner in which REDD+ incentives are to be distributed. Although the programme has consulted households on the best way of distributing incentive funding, the experience from previous projects has shown that community leaders are the ones who benefit more with regard to project funds.

The coefficient estimates of the dummy variables for awareness that deforestation and forest degradation is not good for environment and awareness about REDD+ incentives have opposite signs in the selection and outcome equations. They both increase the probability of participating in the programme but decrease the minimum amount that the household is willing to accept to participate. The marginal results for the dummy variables in the selection equation show that willingness to participate in the programme increases by 10.9 percent for the households that are aware that deforestation and forest degradation are not good for the environment. The marginal effects results for the dummy variable measuring household awareness of REDD+ incentives has opposite signs in the selection and outcome equations. Being aware that there are economic incentives for participating in the REDD+ programme increases the willingness of household to participate by almost 7 percent. At the same time, the households that are aware of these incentives are willing to accept roughly 33 Tanzanian shillings less than those who are not aware of the incentives. This might be because those who are aware of the economic incentives provided by the programme are also aware of the amount offered and this acts as a reality check for their demands.

Finally, the inverse mills ratio is also statistically significant. This means it supports the use of the Heckman model with our data. The coefficient is negative (-0.607), suggesting that, on average, unobservable factors that increase the probability of willingness to participate in the programme decrease the minimum amount the household is willing to accept.

Table 5.3: Heckman Sample Selection model includes income from forest products

	Outcome equation: minimum amount willing to accept		**Selection equation: willingness to participate REDD+**	
Variable	**Coefficients**	**Marginal Effects**	**Coefficients**	**Marginal Effects**
Age of household head	-0.003 (0.003)	-0.004 (0.003)	-0.016** (0.006)	-0.001** (0.001)
Highest education level in household	0.006 (0.012)	-0.003 (0.011)	-0.031 (0.026)	-0.003 (0.002)
The size of household	-0.011 (0.015)	-0.017 (0.015)	-0.062** (0.031)	-0.005** (0.003)
Children still at school	-0.039 (0.026)	-0.033 (0.026)	0.063 (0.052)	0.005 (0.004)
Years stayed in the village	-0.003 (0.002)	-0.002 (0.002)	0.009* (0.005)	0.001** (0.0004)
Household head is male#	0.197** (0.083)	0.146* (0.08)	-0.679*** (0.225)	-0.042*** (0.011)
Household head is married#	-0.11 (0.092)	-0.068 (0.089)	0.372 (0.202)	0.037 (0.024)
Awareness that DEF & FD not good for environment#	-0.169** (0.084)	-0.054 (0.077)	0.859*** (0.152)	0.109*** (0.025)
Awareness about REDD+ incentives#	-0.4*** (0.071)	-0.327*** (0.067)	0.688*** (0.159)	0.065*** (0.017)
Household income from forest products	0.11*** (0.022)	0.106*** (0.022)	-0.042 (0.052)	-0.003 (0.004)
The community is targeted for REDD+ rollout #	- 0.409*** (0.074)	-0.433*** (0.072)	-0.233 (0.174)	-0.02 (0.016)
Forest main user is your household#			0.016 (0.153)	0.001 (0.012)

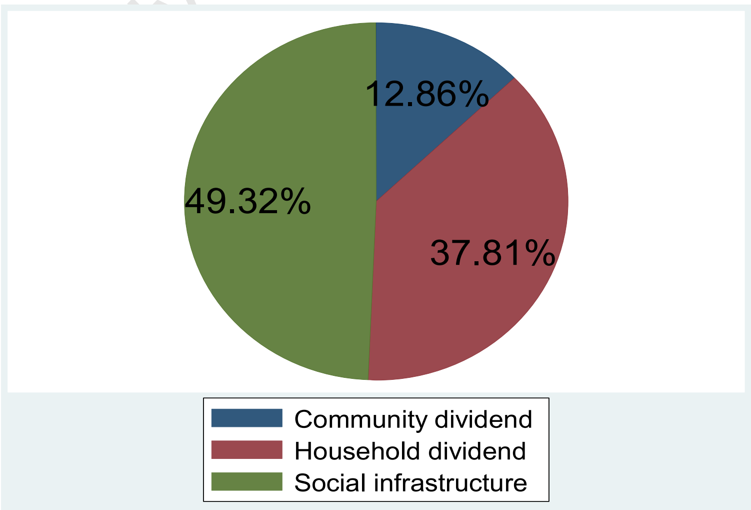
	Outcome equation: minimum amount willing to accept		Selection equation: willingness to participate REDD+	
Time used to collect MIP increase#			0.863*** (0.142)	0.1003*** (0.021)
lambda (Inverse mills ratio) (p chi2)	**-0.607*** (0.0032)**			
Constant	13.966*** (0.338)		1.931** (0.768)	
Observations	**1034**			
Censored Observations	**76**			
Uncensored Observations	**958**			
Log Likelihood	**-1478**			
Wald chi2(10) (p-value)	**179.52 (0.0000)**			

Note:

- *Dependent variable for Outcome equation is the minimum amount the household is willing to accept to participate in REDD+ program; and for the Selection equation is willingness to participate in REDD+ program*
- *Standard errors are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

The results in both regressions reveal that households that are aware that deforestation and forest degradation is not good for the environment have a high probability of participating in the programme. As mentioned earlier, households clear forests for different reasons. Apart from using some forest products for domestic consumption, households mentioned that they generate income from selling some forest products. Although 97 percent of the respondents are aware of the impact of deforestation and forest degradation, the households reported clearing forests in the previous 5 years. Thirty nine (39) percent of the respondents stated that the main reason for them continuing to fell tree are their harsh living conditions. They are involved in harvesting forest products because they need income for their goods consumption. Other reasons mentioned are the need for fuelwood, the need for new fertile land, population growth and the corresponding need for new places of residence, and the need for building materials. Furthermore, the respondents revealed that deforestation and forest degradation can only be stopped if people are given financial support so that they undertake alternative income earning activities; if households are provided with alternative energy for cooking and if people are educated about protecting forests. The respondents further suggested that Government strengthen forest protection and establish and enact strict fines for those caught cutting trees and also pay those who depend on forest products.

As reported earlier, 92 percent of respondents are willing to participate in the programme especially because they are attracted by the financial incentives offered. The respondents, however, have given their opinions on what they think is the best way of compensating households who conserve forests. Apart from asking the programme to pay every household regardless of whether they participate in the programme or not, there are respondents who have suggested that only households who protect forests should be paid and others who suggest that the payments should be made to specific groups. Other respondents have suggested that the programme should build better houses and provide alternative energy for villagers, or develop social services and infrastructure. The study classifies their responses in three categories. Figure 5.6 shows that 49.32 percent of the respondents would like the payments to be channelled through social infrastructure. This includes all payments that are used in building roads, schools, hospitals and other social infrastructures so that everyone benefits. Another group which comprises of 37.81 percent of the respondents suggest the payment should be household dividend. This implies that the payments should be channelled to all households by giving them REDD+ funds. The last category is the 12.86 percent of the respondents that suggested community dividend. This includes asking the programme to build better houses and assist the households' access to alternative energy in the community that is involved in REDD+.



Source: Own survey data, October-December 2011

Figure 5.6: Suggested ways of compensation

5.7 Conclusion and Policy Implications

With a focus on households residing in the regions with massive deforestation and forest degradation, this study finds that, although they are aware of the danger of deforestation and forest degradation, households still clear forests for different purposes. Of course, heterogeneity of forest use still remains an important consideration albeit across communities not within the community. Respondents identified the primary forest users as commercial users from outside the villages. The government needs to accumulate baseline data in order to differentiate incentives in accordance with heterogeneity of forest use across communities. Within the household, men are the main collectors of processed forest products (charcoal and timber) while women lead in collecting unprocessed forest products, mainly firewood. Collecting firewood from dead trees does not contribute to carbon emissions in the same way as charcoal and timber harvesting. In this case, therefore, for the government of Tanzania to earn more credit from the programme, it needs to incentivise male household members with financial support so that they start alternative businesses that will help them to take care of their households.

This study further investigated the willingness of the households to participate, the determining factors of their participation in REDD+, and the determinants of their choice of financial incentives as motivation to participate in the programme**.** Does the amount provided as an incentive play a role in households' decision to participate? The question was answered using the Heckman model that controls for the effects of sample selection.

The selection results from the Heckman model reveal that the variables measuring age of the household head, household size, and household head being male all have a significantly negative effect on the probability of participating in the programme. Households are more willing to participate as the number of years they are resident in the village increases, as they are aware of REDD+ financial incentives. They are also aware that deforestation and forest degradation are detrimental to the environment, and as they note, the time used to collect the most important forest products has increased in recent years. As most respondents are willing to participate, this puts REDD+ in good stead as a promising instrument for restricting deforestation and forest degradation in Tanzania. Knowing that by participating in the programme they are going to receive economic incentives motivates the household to participate. Surprisingly, it appears as if household dividends are not necessary. Perhaps un-selfishness is also part of the reason explaining the 4-fold gap between actual forest income and WTA compensation for full compliance under REDD+. In this case, therefore, the

Tanzanian government is advised to collect baseline data in order to differentiate incentives between the households depending on their forest reliance to motivate them to participate fully.

The results from the outcome equation in the Heckman model reveal that households headed by males and those that earn more from forest products tend to demand more as compensation to participate in the programme. It is expected that a household will only participate in the programme if the compensation is equivalent to that which they are presently earning from forest products. In this case, we expect those who earn more to demand more to participate. The results for the dummy variables for awareness that deforestation and forest degradation is detrimental to the environment, for awareness about REDD+ incentives, and the fact that the community is targeted for REDD+ rollout, decrease the minimum amount that the household is willing to accept. There is a need therefore for the Tanzanian government to educate people about the relationship between REDD+ and climate change so as to increase the cooperation of communities because of the evidence that households that are aware are more willing to participate.

Finally, the study found that 92 percent of respondents are willing to participate in the programme if financial incentives are provided. In order to convince these households, the Government of Tanzania is therefore advised to design compensation in such a way that the households mainly responsible for clearing forests are well incentivised in order for them to cease deforestation completely.

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Appendix 5.1:

Table 5.4: Heckman Sample Selection model includes total income

	Outcome equation: minimum amount willing to accept		**Selection equation: willingness to participate REDD**	
Variable	**Coefficients**	**Marginal Effects**	**Coefficients**	**Marginal Effects**
Age of household head	-0.003 (0.003)	-0.004 (0.003)	-0.016*** (0.006)	-0.001*** (0.001)
Highest education in household	0.005 (0.012)	0.002 (0.011)	-0.031 (0.025)	-0.003 (0.002)
The size of household	-0.011 (0.015)	-0.017 (0.015)	-0.062** (0.031)	-0.005* (0.003)
Children still at school	-0.039 (0.026)	-0.033 (0.026)	0.063 (0.052)	0.005 (0.004)
Years stayed in the village	-0.003 (0.002)	-0.002 (0.002)	0.009* (0.005)	0.001** (0.0004)
Household head is male#	0.196** (0.083)	0.144* (0.08)	-0.679*** (0.225)	-0.043*** (0.011)
Household head is married#	-0.112 (0.092)	-0.069 (0.089)	0.377* (0.202)	0.038 (0.024)
Awareness that DEF & FD not good for environment#	-0.171** (0.084)	-0.056 (0.077)	0.862*** (0.152)	0.109*** (0.025)
Awareness about REDD+ incentives#	-0.402*** (0.071)	-0.329*** (0.067)	0.689*** (0.159)	0.065*** (0.017)
Total household income	0.124*** (0.026)	0.118*** (0.025)	-0.055 (0.059)	-0.005 (0.005)
The community is targeted for REDD+ rollout #	-0.409*** (0.074)	-0.434*** (0.072)	-0.237 (0.173)	-0.021 (0.016)
Forest main user is your household#			0.017 (0.153)	0.001 (0.012)
Time used to collect MIP increase#			0.865*** (0.142)	0.101*** (0.021)
lambda (Inverse mills ratio)	**-0.606*** (0.003)**			
Constant	13.769*** (0.383)		2.112*** (0.868)	
Observations	**1034**			
Censored Observations	**76**			

	Outcome equation: minimum amount willing to accept	Selection equation: willingness to participate REDD
Uncensored Observations	**958**	
Log Likelihood	**-1479.72**	
Wald chi2(10) (p-value)	**177.62 (0.000)**	

Note:

- *Dependent variable for Outcome equation is the minimum amount the household is willing to accept to participate in REDD+ program; and for the Selection equation is willingness to participate in REDD+ program*
- *P values are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively*
- *(#) dy/dx is for discrete change of dummy variable from 0 to 1*

Appendix 5.2: Households' Survey Questionnaire on Reducing Emissions from Deforestation and Forest Degradation (REDD)

Good morning/ Afternoon

My name is Coretha Komba. I am a PhD student at the School of Economics at the University of Cape Town (UCT), South Africa. I am conducting a household survey on reducing emissions from deforestation and forest degradation (REDD). I would like to find out your views about the current discussion on climate change and also I would want to know your willingness to participate in the REDD initiative. Your household has been randomly selected in this important study on climate change. Your participation will be highly appreciated. All answers you provide will be handled confidentially and will be used for research purposes only.

I: Socio-economic variables

1. Households' characteristics

Age of the head of the household……………………………………………….
Years of education of the head of the household……………………………
Years of education of any other member of the household with the highest education…………………………………………………………………
Gender of the head of the household…………………………………………
Size of the household……………………………………………………..
How many are still in school ……………………………………………….
Marital status of the head of the household…………………………………..
Village of the household………………………………………………………….
For how long have you been living in this village…………………………….
District of the household………………………………………………………
Region of the household……………………………………………………
Date of the interview…………………………………………………………………

2. Household assets

Type of assets	Asset code	Does any member of your household own [ASSET] at present? 1=Yes 0=No	How many […] do your household own at present?		Year the asset was acquired
			Number	Total estimated value (in TZS)	
Household Assets					
House	001				
Other Buildings	002				
Furniture	003				
Furnishings e.g. carpet, mat, mattress, etc..	004				
Bednets	005				
Household Appliances e.g. Kettle, Flat iron, etc.	006				

Electronic Equipment e.g. TV., Radio, Cassette, etc.	007					
Generators	008					
Solar panel	009					
improved stove (jiko)	010					
Bicycle	011					
Motor cycle	012					
Car	013					
Jewellery and Watches	014					
Mobile phone	015					
Other household assets e.g. lawn mowers, etc.	016					
Enterprise (Agricultural and Non-Agricultural) Assets						
Hoe	017					
Ploughs	018					
Pangas, slashers, etc.	019					
Irrigation drip	020					
Irrigation spinker	021					
Tractor	022					
Wheelbarrows	023					
Pesticide sprayer	024					
Transport equipment for enterprise	025					
Other enterprise equipment	026					

3. Enumerator observe the house characteristics

a. Size of residence building: …………….(area)……………..(unit)

b. Building material:…[*Wood = 1, Bricks (clay) = 2, Stones = 3, Mud = 4, Other = describe]*

c. Roof:………… [*Tiles = 1, Iron sheets = 2, Thatching grass = 3, Other = describe]*

4. Which activities does your family depend on the most for income generation? (Please rank 1, 2, 3,… in the order of importance for the respondent)

Activity	**Ranking**	**Average monthly income**
Crop production		
Livestock keeping		
Forest products (timber, charcoal, firewood)		
Hunting		
Employment on someone else's farm		
Off-farm employment		

Others (please specify) (i) (ii) (iii)		

II: Deforestation and Forest Degradation

Deforestation means a decrease in the area covered by forest. In this study, we are talking about the permanent removal of forest cover and withdrawal of land from forest use, whether deliberate or circumstantial. Forest conversion to pasture, cropland, or other managed uses is considered the same as deforestation unless noted otherwise. On the other hand, forest degradation does not involve a reduction of the forest area, but rather a quality decrease in its condition. It causes the gradual thinning of forests and can lead to deforestation. Forest degradation can result from selective logging, grazing within forests, and fires as well as over cutting for fuelwood and subsistence agriculture.

5. Land categories in the village (approx. area in hectares).

Land category *(code-land)*	Total area (ha)	Ownership (ha)			
		State	Community	Private	Open access
Forest (please mention):					
1.					
2.					
3.					
Agricultural land:					
4. Cropland					
5. Pasture (natural or planted)					
6. Agroforestry					
7. Fallow					
Other land categories:					
8. Shrubs					
9. Grassland					
10. Residential areas, infrastructure					
11. Wetland					
12. Other, specify:					
13. Total land					

6. **(a)** What are the main forest types, users and products in the village?

Type of forest *(code- forest)*	**Ownership**[1] *(code-tenure)*	**Total area** *(ha)*	**Main users**[2] **(max. 3)** *(code-users)*			**Main products**[3] **(max. 3)** *(code-product)*		

1) Codes: Choose the most appropriate

1=State

2=Community

3=Private

4=Open access

2) By "main users" is meant those who have acquired the highest value of forest products subsistence and cash) from a given forest type in the past 12 months.

Codes: Choose the most appropriate among the following groups (as some do overlap):

1= you and your household

2= other households in the village;

3 = small-scale commercial users in the village;

4 = large-scale commercial users in the village;
5 = households from outside the village;

6 = small-scale commercial users from outside the village;

7 = large-scale commercial users from outside the village;

8 = other, specify:

3) Main products mean forest products which are mainly used.

Codes: Choose the most appropriate among the following:

1=Firewood or charcoal

2=Timber or other wood

3= Food from the forest

4= Medicine from the forest

5= Forage from the forest
6= Other (please specify)

6. (b)

1. How far is it from the house/homestead to the edge of the nearest natural or managed forest that you have access to and can use?	1. … measured in terms of distance	km
	2. … measured in terms of time (in minutes of walking)?	min
2. Does your household collect firewood? *If 'no', go to 8.*	Yes ☐ No ☐	

3. **If 'yes'**: how many hours per week do the members of your household spend on collecting firewood for family use? (adult time should be reported; child time = 50 % of adult time)	(hours)
4. Does your household now spend more or less time on getting firewood than you did 5 years ago? ***Codes:*** *1=more; 2=about the same; 3=less*	
5. How has availability of firewood changed over the past 5 years? ***Codes:*** *1=declined; 2=about the same; 3=increased* *If code '2' or' 3', go to 7*	

6. **If declined** (code '1' on the question above), how has the household responded to the decline in the availability of firewood? *Please rank the most important responses, max 5.*	**Response**	**Rank 1-5**
	1. Increased collection time (e.g., from further away from house)	
	2. Planting of trees on private land	
	3. Increased use of agricultural residues as fuel	
	4. Buying (more) firewood and/or charcoal	
	5. Buying (more) commercial fuels (kerosene, gas or electricity)	
	6. Reduced the need for use of fuels, such as using improved stove	
	7. More conservative use of firewood for cooking and heating	
	8. Reduced number of cooked meals	
	9. Use of improved technology	
	10. Making charcoal	
	11. Other, please specify:	

7. Has your household planted any trees on farm over the past 5 years? *If 'no', go to next section.*	Yes ☐ No ☐

8. **If yes:** what are the main purpose(s) of the trees planted? *Please rank the most important purposes, max 5.*	**Purpose**	**Rank 1-5**
	1. Firewood for domestic use	
	2. Firewood for sale	
	3. Fodder for own use	
	4. Fodder for sale	
	5. Timber/poles for own use	
	6. Timber/poles for sale	
	7. Other domestic uses	

	8. Other products for sale	
	9. Carbon sequestration	
	10. Other environmental services	
	11. To increase the value of my land	
	12 To allow my children and/or grandchildren to see these trees	
	13. Other, please specify:	

6. (c)

1. Did the household clear any forest during the past 12 months? *If 'no', go to 9.*		Yes ☐	No ☐	
If YES:	2. How much forest was cleared?	*(ha)*		
	3. What was the cleared forest (land) used for? *Codes: 1=cropping; 2=tree plantation; 3=pasture; 4=non-agric uses (Rank max 3)*	Rank1	Rank2	Rank3
	4. If used for crops (code '1' in question above), which principal crop was grown? *(code-crops) (Rank max 3)*	Rank1	Rank2	Rank3
	5. What type of forest did you clear? *(code-forest)*			
	6. If secondary forest, what was the age of the forest?	*(years)*		
	7. What was the ownership status of the forest cleared? *(code tenure)*			
	8. How far from the house was the forest cleared located?	*(km)*		
9. Has the household over the last 5 years cleared forest? *If 'no', go to 11.*		Yes ☐	No ☐	
10. **If 'yes':** how much forest (approx.) has been cleared over the last 5 years? *Note: This should include the area reported in question 2.*				
11. How much land used by the household has over the last 5 years been abandoned (left to convert to natural re-vegetation)?				

Code-crops: 1=Maize; 2=Rice; 3=sorghum; 4=cassava; 5=Potatoes; 6=onions; 7=Tomatoes; 8=sugarcane; 9=Other (Please specify)

7 What are the quantities and values of unprocessed and processed forest products the members of your household collected for both own use and sale over the past month?

Note: The quantities of unprocessed forest products used as inputs in making processed forest products

1. Product *(code-product)*	2. collected by who?[1]	Collected where?	5. Own use (incl.	6. Sold (incl. barter)	7. Quantity collected (5+6)	8. Unit	9. Price per Unit	10. Gross value (7*9)	11. Transport/ marketing costs	12. Net income excl. costs of forest

				gifts)				(TZS)			inputs (10-11)
		3. Land type *(code land)*	4. Ownership *(code tenure)*								

1) Codes: 1=only/mainly by wife and adult female household members; 2=both adult males and adult females participate about equally; 3=only/mainly by the husband and adult male household members; 4=only/mainly by girls (<15 years); 5=only/mainly by boys (<15 years); 6=only/mainly by children (<15 years), and boys and girls participate about equally; 7=all members of household participate equally; 8=none of the above alternatives; 9=person employed by and living with the household.

8

	Firewood	Charcoal	Timber or other wood	Food from the forest	Medicine from the forest	Forage from the forest	Other
1. What is the most important product (MIP) for the livelihood of the people in the village (in this category)?							
2. How has availability of the MIP changed over the past 5 years? ***Codes:*** *1=declined; 2=about the same; 3=increased*							

3. If the availability of the MIP in this category has **declined**, what are the reasons? *[Please rank the most important reasons, max. 3 (leave rest Blank)]*	**Reason**	**Rank 1-3**
	1. Reduced forest area due to small-scale clearing for agriculture	
	2. Reduced forest area due to large-scale projects (plantations, new settlements, etc.)	
	3. Increased use of MIP due to more local (village) people collecting more	
	4. Increased use of MIP due to more people from other villages collecting more	
	5. Restrictions on use by central or state government (e.g., for forest conservation)	
	6. Local restrictions on forest use (e.g., community rules)	
	7. Climatic changes, e.g., drought and less rainfall	
	8. Timber harvesting	
	9. Charcoal burning	
	10. Brick burning	

	11. Poor harvesting practices	
	12. Bush burning	
	13. Increased marketing potential for product	
	14. Other, please specify:	
4. If the availability of the MIP in this category has **increased**, what are the reasons? *(Please rank the most important reasons, max. 3.)*	**Reason**	**Rank 1-3**
	1. Less clearing of forests for agriculture (incl. pastoralism)	
	2. Fewer local (village) people collecting less	
	3. Fewer people from other villages collecting less	
	4. Reduced use from large-scale commercial users/projects	
	5. Changes in management of forests	
	6. Climatic changes, e.g., more rainfall	
	7. Forest clearing that increases supply of product (e.g. fuelwood)	
	8. Tree planting	
	9. More illegal access of protected area	
	10. Improved access rights to product	
	11. More secondary forest (as people clear land and forest regenerates)	
	12. Other, please specify:	
5. What would be most important to increase the benefits (use or income) from the MIP? *Please rank the most important reasons, max. 3.*	**Action**	**Rank 1-3**
	1. Better access to the forest/MIP, i.e., more use rights to village	
	2. Better protection of forest/MIP (avoid overuse)	
	3.Better skills and knowledge on how to collect/use it	
	4. Better access to credit/capital and equipment/technology	
	5. Better access to markets and reduced price risk	
	6. Invest in planting trees/forest product	
	7. Develop forest user groups/collective action in harvesting	
	8. Control fire	
	9. Other, please specify:	

9 On average, how much are you getting from newly cleared land (from all forests) per month? (Please Specify)

Reason	**Average amount (in '000 TZS)**				
	<100	110-300	310-500	510-1000	>1000
Income from selling agricultural products					
agricultural products for household consumption					

Income from selling fuelwood					
Fuelwood for household consumption					
Income from selling timber products					
Income from selling bush meat					
Bush meat for household consumption					
Others (please specify) (i) (ii) (iii)					

10 Are you aware that deforestation and forest degradation is not good to the environment? ☐ Yes

☐ No

11 If yes, why don't you stop cutting trees? (Please give the reasons)

(a) …………………………………………………………………….

(b) …………………………………………………………………….

(c) …………………………………………………………………….

(d) …………………………………………………………………….

12 What can we do to make them stop cutting trees? (please advise)

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

III: Climate change and REDD

Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in the rainfall patterns? ☐ Yes

☐ No

13 If yes, has the amount and variability increased or decreased?

14 Comparing the 1990s with the recent past 10 years i.e. 2000s, have you noticed any changes in temperature? ☐ Yes

☐ No

15 If yes, has the amount and variability increased or decreased?

16 Have you observed drought in the past 2 decades?

☐

☐

Yes
No

17 On average, how many times/years have you observed drought in the past 2 decades?

18 Have you observed flood in the past 2 decades?

19 On average, how many times/years have you observed flood in the past 2 decades?

20 Do you know that deforestation and forest degradation lead to emission of carbon dioxide into the atmosphere which scientists have said is the major cause of climate change?

☐ Yes
☐ No

21 If yes, are you willing to take any action(s) to stop deforestation and forest degradation?

☐ Yes
☐ No

22 If yes, what actions do you take? Please specify)

(i)…………………………………………

(ii)……………………………………………

(iii) …………………………………………

(iv)……………………………………………

Introduction to REDD

This study wants to understand if you would want to participate in the REDD programme managed by the Ministry of Natural Resources and Tourism, the Vice Presidents' Office-Environment, NEMC, assisted by [MJUMITA, WWF, SUA, TATEDO, others (please mention……………………….)]. The main purpose of the REDD programme is to reduce deforestation and forest degradation in order to prevent emissions of carbon dioxide from forests and create more sinks to store more carbon stocks in these forests. The programme aims to achieve this by providing payments to either individuals or villages or whole communities who volunteer to reduce deforestation and forest degradation. When individuals or villages or whole communities accept to participate in the REDD programme, it means that they should restrict their use of particular forests to ensure that intact forests continue to exist to capture carbon stocks. The additional carbon stocks which will be generated over years would form the basis for financially rewarding people (either individuals or villages or whole communities) who have contributed to the continued existence of intact forests. Once the financial rewards have been paid out, the individuals or villages or whole communities *can decide how to use this money: whether to allocate the REDD payment to the individual households or village projects or community projects.*

23 Before the introduction above, have you been aware of the REDD program?

Yes ☐

No ☐

24 If yes, how did you come to know about the REDD program? (Please mention)

(i)……………………………………..

(ii)…………………………………….

(iii)…………………………………….

25 Is REDD program introduced in your community?

Yes ☐ (If yes, answer questions 27 – 32)

No ☐ (If no, skip questions 27 - 32)

26 Were you aware of the concept of forest conservation before the introduction of REDD?

Yes ☐

No ☐

27 If yes, what did you do?

Type of management	**Code[1]**
1. Planting of trees	
2. Cutting down undesired (competing) trees	
3. Protecting areas of forest for particular environmental services, like water catchment	
5. Establishing clear use rights for a limited number of people to particular forest products (e.g. honey trees)	
6. Extension/education about forest management	
7. Enacted bylaw (e.g., no bush burning in or near forest)	
8. Other, specify:	

1) *Codes: 0=no, not at all; 1=yes, but only to a limited extent; 2=yes, they are common*

28 Do you see any changes in your nearby forests after the introduction of REDD?

Yes ☐

No ☐

29 If yes, can you say that (mark the appropriate box)

(i) Deforestation has increased

(ii) Forest degradation has increased

(iii) Deforestation has decreased

(iv) Forest degradation decreased

(v) Deforestation has remained the same

(vi) Forest degradation has remained the same

30 In your opinion, is the REDD program useful for protecting forest in your community?

Yes ☐

No ☐

31 If no, how would you want it to be? (Please explain)

....
....
....

32 In your opinion, do you think the REDD programme is going to help your household?

Yes ☐

No ☐

33 If yes, how is the programme going to help your household? (Please explain)

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

34 If no, how would you want it to be? (Please explain)

....
....
....

35 In response to question 23 above, which actions will you take only in connection to the REDD programme? i.e. those you will take simply because you will eventually get paid if they help to keep the forest intact

(i)…………………………………..

(ii)………………………………….

(iii)………………………………….

36 Are you aware that the REDD programme intends to provide economic incentives for individuals or group to participate in forest conservation?

Yes ☐

No ☐

37 Do you think paying people to stop cutting trees will be effective in preventing deforestation and forest degradation?

Yes ☐

No ☐

38 If yes, why? (please explain)

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………

39 If no, what do you think would help to get people to stop deforestation and forest degradation? (please explain)

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………

40 Participating in the REDD programme means your household is completely restricted from using particular forest(s) for whatever uses in order to help completely stop deforestation and forest degradation. **This implies that every year your household will lose the benefits which you indicated in question 8. However, your household would also receive financial payments (either directly or as part of the village or community) based on the additional carbon stocks captured by the particular forest(s) which your household normally uses**.

Is your household willing to participate in the REDD programme connected to the forest(s) which you normally use?

Willingness	For which forest(s)	Distance to the forest(s)
Yes		
No		

41 Are you willing to comply with all the use restrictions which will be imposed?

Comply	For which forest(s)	Distance to the forest(s)
Yes		
No		

42 For those forest(s) in which you do not want to fully comply, which few restrictions are you willing to comply with?

Activity	By how much per month in forest (i)?	By how much per month in forest (ii)?	By how much per month in forest (iii)?
Stop clearing land for agriculture only			
Stop cutting trees for fuelwood only			
Stop cutting trees for timber products only			
Others (please specify) (i) (ii) (iii)			

43 What is the **minimum amount** (in Tanzanian shillings) that you and your household will be willing to accept as compensation for your household to completely stop cutting trees for fuel wood, timber products, clearing new land for agriculture etc every year as you are currently doing as reported in question 6 (b) and (c)?

Activity	Minimum amount willing to accept as REDD payment for actual compliance action
Stop clearing land for agriculture	
Stop cutting trees for fuel wood	
Stop cutting trees for timber products	
Others (please specify) (i) (ii) (iii)	

44 In your opinion, what is the best way of compensating individuals who conserve forests? (Please explain)

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…………………………………………………………………………………………

45 What future expectations do you have in relation with REDD programme? (Please explain)

…………………………………………………………………………………………
…………………………………………………………………………………………

THANK YOU

Chapter 6: Summary and Conclusion

6.1 Summary

There is near consensus among environmental scholars that climate is changing. In recent years, studies on climate change have found substantial evidence showing that global warming is being driven by human activities that include regular burning of fossil fuels, deforestation and other changes in land-use which result in an increase in the emission of greenhouse gases into the environment (see for example Stern, 2007; Van Aalst, 2006). While many sectors of production in developing countries are affected by climate change, agriculture is the main victim of the negative impacts brought about by variability of temperature and rainfall. This is because the agricultural sector, which is the dominant sector in most developing countries, is predominantly rain-fed.

This thesis set out to contribute to the literature in three broad aspects. First, it analyses the potential role of effective adaptation methods in reducing farmers' vulnerability to climate change in Tanzania. Second, it investigates approaches to the choice of adaptation methods in reducing farmers' vulnerability to the impact of climate change. Third, it examines the willingness of households to participate in Tanzania's REDD+ programme to cope with climate change. The study uses two datasets to investigate these issues. The first dataset is used to analyse smallholder farmers' vulnerability and adaptation to these changes. The second dataset is used in investigating households' willingness to participate in the United Nations Collaborative Program on mitigations towards climate change.

Survey data is collected from 556 randomly selected farmers' households during the period December 2010 to January 2011 in four administrative regions of Tanzania (Iringa, Morogoro, Dodoma, and Tanga) in order to investigate the characteristics of farmers' households who are most likely to face future poverty. The data were collected from farmers using a structured questionnaire and face-to-face interviews conducted in Kiswahili, which is Tanzania's national language and is spoken by the majority of Tanzanians. Farmers were asked to compare the climate in the period 1990 to 2010 with respect to mean and variance precipitation and temperature. Farmers who reported they had observed changes were asked about the ways in which they responded to these changes. About a third (34 percent) of the surveyed farmers did not undertake any adaptation strategies. The reported dominant methods of adaptation of those that did, were planting short season crops, planting drought resistant crops, altering planting dates, planting trees, and irrigation.

An overwhelming majority of the farmers (98.9 percent) reported that they had observed mean and variance changes in both precipitation and temperature. Mean precipitation was perceived to have decreased while the variance of precipitation was perceived by some farmers to have increased. Others thought that both the mean and variance of temperature had increased. Thus, there is sufficient evidence that Tanzanian smallholder farmers recognise that climate change has occurred over the two decades covered by the study. Statistical evidence from data provided by the Tanzanian Meteorological Agency indicates a decrease in mean decadal rainfall and an increase in mean decadal temperature as well as an increase in the decadal variances of both rainfall and temperature in this period, consistent with the farmers' perceptions.

Chapter Three of the study analyses the data by empirical estimation testing the effect of the effective adaptation methods that have an impact on reducing farmers' vulnerability to climate change, using the vulnerability as expected poverty (VEP) approach. The weighted FGLS results reveal that farm size, distance from output market, average annual rainfall, and growing maize and rice as major crops tend to increase farm income. It is expected that the farmers' households will be able to increase their income and hence save for the future if the mentioned variables are favourable.

At the time of the survey nearly a fifth (18 percent) of the surveyed households were poor; and almost half (52 percent) had a more than 50 percent chance of falling into poverty in the future. The latter is the group that is vulnerable. Overall, the study finds that the number of vulnerable households is three times higher than the number of poor households. In comparison to female headed households, male headed households are found to be more susceptible to future poverty. Surprisingly the comparison with education levels shows that the households with members with more than primary school education are more vulnerable. Large households (with more than 10 household members) also appear to be more vulnerable.

The study also observed that farmers who have received agricultural support from either the government through their agricultural officers or from other farmers are less at risk. The study further indicates that in households that are above the vulnerability threshold, there is a positive relationship between the level of vulnerability and the farmers' income derived from farm outputs. It is also found that many farmers' households that are currently poor and vulnerable prefer to use crops that are resistant to drought as their dominant adaptation method. Considering that most poor farmers that have implemented adaptation methods to deal with the negative effects of climate change have remained poor, there is the impression that these adaptation methods are not appropriate.

The study used a binary logit model to identify what determines the probability of farmers' households being currently poor or falling below the poverty line in the future. The results for vulnerability indicate that the probability of farmers' households being vulnerable increases with an increase in education in the household, with farm size, and distance from output markets. The likelihood decreases with the age of the household head, household size, access to credit, growing maize and sorghum as major crops, and using short season crops as a dominant adaptation method. In analysing vulnerability to climate change, the results reveal that climate variables like rainfall, temperature, and incidence of flood over the past 20 years have a significant impact on farmers' current and future poverty. Farmers who experienced incidences of flood are more likely to be vulnerable than those who have not. This motivates us to go further and analyse the factors contributing to farmers' choice of adaptation methods.

In the second section, the study focuses on the factors influencing farmers' choice of adaptation methods to deal with climate change. Chapter Four looks at the relevant adaptation methods which Tanzanian farmers choose to implement so as to reduce the negative impacts of change on their agricultural yields. A Heckman sample selection model is used to estimate the probability of farmers adapting and the factors relevant to choosing a certain adaptation method. The results on the inverse Mill's ratios suggest a strong selection mechanism in three adaptation choices. Therefore, the sample selection issue needed to be addressed. The coefficients -0.569, -0.546 and 0.326, suggest that, on average, unobservable factors that increase the probability of farmers adapting, decrease their likelihood of choosing to plant short season crops and change planting dates, and increase their likelihood of planting crops resistant to drought.

Estimation results of a selection equation (binary probit model) demonstrate that the probability of a typical Tanzanian farmer adapting to climate change increases with an increase in years of education in the household, having observed climate change with respect to precipitation and temperature across the two decades, the frequency of drought experienced during the 20 years, growing rice as the major crop, and the agro-ecological zone. The results also suggest that the probability of undertaking adaptation decreases with temperature and rainfall levels in the farming area, and with distance from input market. Farmers located in the coastal and plateau agro-ecological zones tend to adapt more often compared to those located in the arid agro-ecological zone.

Results of the outcome equation estimation (multinomial probit model) of farmer's choice of adaptation method show that the probability of using short-season crops increases with temperature intensity, having received agricultural technical support from community groups or government, and being located in the coastal agro-ecological zone, and decreases with growing rice as the major crop. The results also reveal that the probability of using crops which are resistant to drought increases with an increase in years of education in the household, temperature intensity, and incidence of drought; and decreases with being located in the coastal, alluvial plains, southern highlands, and semi-arid agro-ecological zones.

It is further observed that the likelihood of using irrigation increases with rainfall intensity, and being located in the alluvial plains, southern highlands, and semi-arid agro-ecological zones, and decreases with growing rice as the major crop. In addition, the results indicate that the likelihood of changing planting dates increases with experience of incidence of flood but decreases with an increase in education in the household, rainfall intensity, access to credit, access to media, incidence of drought, and being located in the semi-arid and southern highlands agro-ecological zones. It is also demonstrated that the probability of planting trees as an adaptation technique decreases with growing rice as the major crop, and with rainfall intensity.

The study indicates that farmers in Tanzania are making an effort to cushion themselves against climate change by choosing the adaptation methods they are able to depending on different factors. It is important for them to do so as individuals but it is also important for the farmers to join in the international efforts to mitigate climate change. We investigate the willingness of Tanzanian farmers' households to participate in climate change mitigation under the United Nations Collaborative Program on REDD+. Reducing deforestation and forest degradation is an important component of slowing down greenhouse gas emissions (World Development Report, 2010). However, asking households to reduce deforestation means asking them to sacrifice the important direct benefits they receive from forests. The REDD+ programme provides a way in which to compensate households. The programme seeks to decrease emissions by paying countries for reducing deforestation and forest degradation.

To investigate households' willingness to join the programme and accept financial compensation to participate in REDD+ programmes, this study uses a second dataset from a survey conducted in seven administrative regions in Tanzania (Coast, Tanga, Dodoma, Morogoro, Iringa, Lindi, Shinyanga) that includes 1034 randomly selected households. The regions were purposely selected because of their high incidence of deforestation and forest degradation and some districts in two of the surveyed regions have launched the REDD+ programme. It is observed that, 78 percent of the households surveyed are aware that deforestation and forest degradation is detrimental to the environment. An estimated 59 percent of the households are aware of REDD+ economic incentives, and 33 percent of the respondents reported that their communities are targeted for REDD+ rollout. Eighty-nine percent said that the time that the household uses to collect the most important forest products has increased compared to previous years. The households indicated that they would participate in REDD+ if the programme could compensate them with a minimum of 3.3 million Tanzania Shillings (which is equivalent to USD 2072) on average. This is higher than the median of 2 million Tanzania shillings. The statistics show that the amount they demand to participate in the programme is 426 percent more than their current forest income. This is expected since we know from the endowment effect hypothesis that people tend to assign more value to things they own than those they could obtain.

Using Heckman's sample selection model for willingness to participate and accept compensation from the REDD+ programme, the study finds that the variables measuring age of the household head, household size, and male household head all have significantly negative effect on the probability of participating in the programme. Households willingness to participate in the programme increases in relation to the years the household has stayed in the village, the more they know about REDD+ financial incentives, and the more they are aware that deforestation and forest degradation is not good for the environment, and as they note that the time used to collect the most important forest products has increased in recent years.

The Heckman model also reveals that households that are headed by males and those that earn more from forest products tend to demand more as compensation to participate in the programme. It is expected that a household will only participate in the programme if it is compensated an equivalent of what it is presently earning from forest products. In this case, we expected those who earn more from forest products to demand more for them to participate. The results for the dummy variables for awareness that deforestation and forest degradation is detrimental, for awareness about REDD+ incentives, and for capturing the fact that the community is targeted for REDD+ rollout suggest that this awareness decreases the minimum amount that the household is willing to accept to participate in the programme.

The study results reveal that households that are aware that deforestation and forest degradation is harmful have a high probability of participating in the programme. As indicated earlier, households clear forests for different reasons. Apart from using some forest products for domestic consumption, households mentioned that they generate income from selling some of these products. Other reasons mentioned are the need for fuelwood, the need for new fertile land, population growth and the corresponding need for new places of residence and building materials. Furthermore, the respondents revealed that deforestation and forest degradation can only be stopped if people are given financial support so that they undertake alternative income earning activities, if households are provided with alternative energy for cooking, if people are educated about protecting forests, and if the government establishes and enforces strict fines for those caught cutting trees. Government can also choose to pay those who depend on forest products.

6.2 Recommendations and policy implications

While our result suggests that smallholder farmers in Tanzania perceive climate change, are making some effort to cushion themselves by adapting to these perceived changes and are willing to participate in the United nations Collaborative Program on mitigation towards climate change, it is important to identify the characteristics of farmers who are not only more vulnerable to climate change but also more willing to participate in the programme.

The results of this study confirm that apart from farmers perceiving climate change and responding to their perception by undertaking adaptation measures, the choice of adaptation method matters vary. Therefore, the major role that the Tanzanian government needs to occupy itself with regarding the effects of climate change on smallholder agriculture is to help farmers overcome the constraints they face in choosing appropriate adaptation methods. There is a need for the government to develop irrigation infrastructure especially in the arid agro-ecological zone to assist farmers in their agricultural activities in order to reduce their vulnerability.

When designing policy that will reduce farmers' vulnerability, this study recommends that the Tanzanian government should formulate policies that target those groups of farmers. Flood, drought and other natural disasters result in many losses for agriculture, and the government of Tanzania needs therefore to introduce affordable agricultural insurance to compensate farmers for their losses. The government should also provide education to farmers on the type of crops suitable for the amount of rainfall and temperature in specific agricultural areas.

Undertaking some form of adaptation to climate change is a step in the right direction by farmers in Tanzania given the evidence that such change is occurring in the country. However, different adaptation methods have different levels of effectiveness and may be preferred over others. Furthermore, particular adaptation methods might be more appropriate for particular crops or agro-ecological zones. The government can play a significant role by promoting adaptation techniques appropriate for particular circumstances. In order to do so, the government requires information about the key drivers of the current choice of adaptation methods. This information should cover the social characteristics of farmers who are likely to voluntarily adopt particular methods, and the environmental, institutional and economic conditions influencing their adoption of these strategies. The former gives guidance in targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change. The latter gives guidance about the environmental, institutional and economic conditions which need to be changed to promote particular adaptation strategies.

The findings of this study offer guidance towards targeting farmers' recruitment into initiatives aimed at enhancing adaptation to climate change using particular methods as well as guidance about the environmental, institutional and economic conditions which need to be reformed to promote particular adaptation methods. The government should encourage farmers who reside in the drier agro-ecological zones (the arid and semi-arid zones) to concentrate on farming drought resistance crops. It is also recommended that the government develop irrigation infrastructure in areas where water is available.

There is need for the Tanzanian government to educate people on the relationship between REDD+ and climate change. The government is also advised to collect baseline data in the villages targeted for REDD+ rollout to differentiate incentives between households which rely on forests to ensure their full participation in the programme.

The study also finds that despite their awareness of the danger of deforestation and forest degradation, people still clear forests for financial reasons. In this case, in order for the government of Tanzania to earn more credits from the programme, it needs to compensate forest users with financial support so that they start alternative businesses that will help them take care of their households.

The REDD+ programme is designed to provide financial incentives to every household regardless of whether or not they participate in the programme. However, some respondents have suggested that only households who protect forests should be paid while others have suggested that the payments should be made to groups active in conserving forests. Other respondents have suggested that the programme should build better houses and provide alternative energy for villagers; or develop social services and infrastructure. In order to convince the households who are willing to participate in REDD+ to participate in the programme, the government of Tanzania is therefore advised to design compensation in such a way that the households who are largely involved in clearing forests are well incentivised in order for them to contribute to an end to deforestation.