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Existing Research and Knowledge on Impacts of Climate Variability and Change on Agriculture and Communities in Malawi

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Executive Summary

The goal of the integrated Malawi research activities conducted in 2014 and 2015 was to provide new information for the Malawian government, researchers, and communities to improve crop productivity and enhance resilience to climate change and variability. This study summarizes existing knowledge and research, as well as gaps, on impacts of and responses to climate change (CC) on agriculture and farming communities in Malawi based on a review of published and gray literature. This includes farmer and scientific perceptions and implications of past and projected climate variability and change, national policy responses and adaptation strategies taken mainly by local farming households and communities, and factors influencing their adoption. It also examines gaps in adaptation research and capacity, and discusses broader implications of the study. [1]

Malawi is among the world's dozen countries most vulnerable to adverse effects of climate change (CC), and among those with the least resources to adapt or mitigate them. Its agriculture sector is most vulnerable to climate shocks, particularly droughts and flooding. This threatens food security, a third of Malawi's agro-driven Gross National Product (GNP), a major share of exports value, and the livelihoods of 85% of Malawi's predominantly rural and densely distributed 16 million people. Most are poor farmers subsisting on less than $1 USD a day and dependent on low-input, low-output rain-fed agriculture, and small landholdings. This limits their CC adaptation options and capacity. Inadequate research and actionable information on current and future CC and impacts and effective solutions undermines planned adaptation.

Farmer and scientific perceptions of recent climate variability/change agree on temperature but diverge on rainfall. Both show increasing trends in temperatures (0.9°C observed 1960-2006); dry days, hotter summers, drought and flood frequency, and inter-annual variability in rainfall. Contrary to common farmer perceptions of declining total annual rainfall and their delayed start and earlier cessation, no study showed evidence of significant long-term shifts in total rainfall and timing. However, one study discovered a significant geographic (north versus south) and temporal (before and after a detected dry spell in mid-February) bifurcation in Malawi's rainfall and circulation regime that can aid future CC projections. The discordant CC perceptions can undermine adaptation via mistargeted, suboptimal, and locally inappropriate strategies, or short-lived coping or reactive rather than long-term anticipatory or proactive strategies or maladaptive ones. They undermine farmer confidence in, and use of, formal climate information and related extension advice. Successful adaptation requires reconciling these perceptions to ensure that famers, extension agents, managers, policy makers, and scientists understand what is changing with weather/climate, as well as how, where, and what they can do.

Amid significant uncertainty across (global circulation) models, future CC projections and impacts show spatial and geographic variation, yield and economic gains and losses, winners and losers. Mean annual temperatures are projected to increase by 1-3ºC by 2050. Annual rainfall projections vary from modest declines or no change to increases of over 45-400 mm. Diverse socio-demographic, economic, ecological, and geographic factors influence CC impacts. Predicted yield changes (2010-2050) range from -25% to +25% for maize. Cotton, cassava, and other tubers show the highest growth potential in production, yield/hectare, and exports.

[1] While primarily based on review of grey and peer-reviewed literature and conducted June-December 2014 by Leo Zulu, the study also uses information (including documents) from a few key informants and observations collected during a visit to Malawi by Leo Zulu and Jennifer Olson in July-August 2014.

Malawi has taken concerted policy and institutional responses to CC, but they remain in infancy, largely in reaction to national reporting obligations under the United Nations (UN) Framework Convention on Climate Change, and driven externally by donors. The Agriculture Sector Wide Approach, the National Adaptation Plans of Action (NAPA), and the Malawi Growth & Development Strategy II are the major policies on CC and agriculture. There is need to move from mainly short-term, crisis-driven planning and coping (autonomous) strategies to long-term, science-based (anticipatory) ones; from short-term coping projects to long-term adaptation programs. CC-related sector policies and implementation remain disjointed, mainstreaming of CC adaptation limited, and institutions weak, overlapping, or contradictory. CC data and information is poor, limited, and largely disconnected from policy and program decision-making, and implementation resources (financial, human, and technological) remain scarce. However, a much more comprehensive draft national climate change policy awaiting cabinet approval at least recognizes many of these challenges and seeks to address them.

Many farmers have adopted diverse, autonomous, and induced strategies to perceived climate variability and change. Strategies include (a) inputs (drought/heat resistant, early maturing and high yielding varieties, organic and inorganic fertilizers); (b) practices (small-scale irrigation, crop diversification, and adjusting planting times and density); and (c) climate smart agro-ecological cropping and sustainable land management (SLM) systems such as intercropping, conservation agriculture elements (minimum/no till, crop cover/mulching and crop rotation), integrated crop/livestock systems, agroforestry, tree planting, and soil/water conservation. Diverse, site- and crop-specific factors influence adoption of strategies. Access to extension services is universally important. Wealthier households with more land are more likely than poor farmers to adopt both modern (improved seeds and chemical fertilizers) inputs and SLM strategies. Landowners with more and tenure-secure land tend to adopt SLM strategies; those with insecure tenure and/or more off-farm incomes prefer modern inputs. Higher food insecurity or labor supply, and perception of drought risk or biophysical sensitivity, enhance adoption of SLM. Men tend to benefit more from modern, and women from more holistic, SLM strategies. Other factors are age and education; policies, local institutions, and social capital; markets (inputs costs, commodity prices, and access to credit, markets and technology); and biophysical factors.

There is a dearth of research on scaled-down future projections of CC, their impacts on agriculture isolated from contextual factors, and development and/or screening of (best bet) adaptation strategies that demonstrate proof of concept to enhance adoption and scaling up. Integrating traits that farmers prefer (e.g., storability, pest/disease resistance, and taste) with more robust drought resistance in diverse crops is also needed. Research gaps remain on production and packaging, access, and use of climate information for decision making by farmers and policy makers, and on CC policy impact analysis. Gender-differentiated vulnerability to and impacts of CC, and women's interests and their contributions to adaptation are understudied; so are livestock and livestock/crop systems, pests, and diseases in relation to CC.

Major research capacity gaps exist. They include data availability/quality, human analytical capacity, financial resources and research infrastructure, and institutional support. Human capacity needs for research include modeling (CC projections, crop modeling, mathematical and dynamic modeling, and participatory modeling decision-making), geospatial analysis, integrated/interdisciplinary analysis, and core disciplinary training (climate change science, meteorology, and climate change adaptation, social policy analysis and impact evaluation).

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Acronyms

ASWAp	Agriculture Sector Wide Approach
CA	conservation agriculture
CARLA	Climate Adaptation for Rural Livelihoods and Agriculture
CC	Climate Change
DARS	Department of Agricultural Research Services
DfID	(British) Department for International Development
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization of the United Nations
FISP	Fertilizer Input Subsidy Program
GAP	good agricultural practices
GCM	Global Circulation Model
GoM	Government of Malawi
IBWI	Index-based weather insurance
IFAD	International Fund for Agricultural Development
IRLAD	Irrigation, Rural Livelihoods, and Agricultural Development Project
LDC	Least Developed Country
MGDS II	Malawi Growth and Development Strategy (Second)
NAPA	National Adaptation Plans of Action
NCCIP	National Climate Change Investment Program
NGOs	Non-governmental Organizations
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SAPP	Sustainable Agricultural Production Program
SLM	Sustainable Land Management
SWC	Soil and Water Conservation
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar ($)

1. Introduction

Malawi (particularly its agriculture sector) is vulnerable to negative impacts of current and future climate change (CC),[2] given its heavy dependence on small-scale, low-input/low-output, rain-fed agriculture for food security, incomes/livelihoods, and on exports for national socio-economic development under the challenging context of dire poverty, rapid population growth, small land parcels, and environmental degradation, including soil erosion, already erratic rainfall, and weak institutions and coordination. Malawi has been ranked by the World Bank among the 12 most vulnerable countries in the world in two of the six major global CC threats (drought and impacts on the agriculture sector), Mearns and Norton (2010). The Climate Change Vulnerability Index places the country among the world's top 15 countries in the "extreme risk" category (Maplecroft undated). These CC vulnerabilities are highly significant because agriculture is the kingpin of Malawi's national economy and development. Agriculture accounts for a third of the economy (30.2% of gross national income in 2011) and 80% of total export value, with tobacco and tea accounting for 71.5% of total exports in 2012 (Government of Malawi (GoM) 2011a; Chinsinga, Chasukwa, and Naess 2012; World Bank 2014). Over half (51%) of Malawi's predominantly rural (86%) population live below the national poverty line, most (85%) dependent on agriculture for livelihood, and on only $320 United States Dollars (USD) per capita per year (Chinsinga, Chasukwa, and Naess 2012; World Bank 2014). Relative to commercial or estate agriculture, the smallholder farmers' sub-sector dominates Malawi's agricultural sector, constituting 78% of cultivated land and 75% of agricultural production (Asfaw et al. 2014). However, most smallholder farmers (>72%) cultivate less than a hectare of land, sufficient to meet their current subsistence food needs. Further, Malawi's staple, maize, dominates all crops and covers 70% of arable land, but only 10% of maize growers attain net seller status; 60% are net buyers (Asfaw et al. 2014). Thus, within agriculture, the smallholder agriculture sub-sector is particularly vulnerable to adverse CC impacts.

The Malawi government has responded to the threats that CC poses through concerted policy and institutional arrangements and programs both to adapt to and mitigate the adverse impacts of CC. However, these policy efforts and adaptation planning and implementation are still in infancy and evolving amid daunting financial, human, and institutional capacity limitations. Donor agencies have played a major role in policy formulation and funding of early projects, with an increasing role for non-governmental organizations (NGOs). Farmers, already experiencing climate variability and change, have adopted diverse coping and some adaptive strategies autonomously or induced by extension agents or NGOs (e.g., Oxfam 2009; Magombo et al. 2012; Wellard, Kambewa, and Snapp 2012; Fisher and Snapp 2014). However, despite recognition of the important role of research in CC responses in some policy documents, there remains a dearth of research and knowledge on future projections and impacts of CC on agriculture, farming communities and their livelihoods and the economy, also on adaptive strategies for particular crops and agro-ecological and socio-economic settings, which is needed to guide effective planning and implementation of "proactive" (or strategic) long-term adaptation strategies to future CC (Stringer et al. 2009; Asfaw et al. 2014; Mwase et al. 2013; Gama et al. 2014). A growing but still limited amount of research has been done on local perceptions of CC and on identifying, documenting, disseminating and promoting mainly coping (reactive or tactical) or autonomous adaptation strategies against past, short-term weather variability and change. However, there remains a "disconnect between climate science and African agriculture" in terms of its use in policy and farmer-level decision making and the more immediate research role

[2] More than 99% of Malawi's approximately three million hectares of cultivated land is under rain-fed agriculture, and in 2005 only 0.47% was irrigated (GoM 2011a).

in facilitating the needed "move from awareness raising to proof of concept" (Ziervogel et al. 2008). Malawi is no exception.

This study summarizes existing knowledge and research, as well as gaps, on impacts of climate change (CC) on agriculture and farming communities in Malawi, based on a review of published and gray literature. Conducted between June and December 2014, it also examines research on farmer and scientific perceptions of the past (4-5 decades) climate variability and change and implications thereof, along with projections and impacts of future CC, national policy adaptation responses, and strategies adopted by local farmers and factors influencing their adoption. It also briefly examines gaps in adaptation research and capacity before concluding.

2. Methodology

This was primarily a desk study involving a review of existing peer-reviewed and grey literature on the impact of and adaptation to climate variability and change in Malawi with a focus on the agricultural sector and farming communities. Multiple standard bibliographic searches, including Google Scholar, Scopus, and Web of Science were used for scholarly literature based on various combinations of key words on climate change impacts and adaptation in agriculture in Malawi. Regional studies on southern or Sub-Saharan Africa, where appropriate, are used sparingly to inform the review on Malawi. Regular Google searches were used to seek relevant gray literature—national or international study or project reports/documents, government policy and strategy documents, and international agency, donor and NGO documents.[3] In addition to gray literature collected by the author and ongoing interactions with various government, university, donor, and NGO sources in and related to Malawi, other documents were collected during a three-week visit to Malawi in July/August 2014, which included information from a small number of key informants.[4] Information reviewed includes background information on the agricultural sector and CC issues, empirically observed weather/climate trends of the past 4-5 decades, policy responses, local perceptions of and responses to weather/climate trends and driving factors to their adoption, future CC projections and impacts on agriculture and farmers, performance of adaptation strategies including farmer innovations, and gaps in research and capacity. Gender differentiation was sought in vulnerability, impacts, and costs and benefits of adaptation strategies.

[3] Information on climate change and related sectoral policies, strategies, CC projects and government reports to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat are available at the Malawi Climate Change Program website maintained by the Department of Environmental Affairs in the ministry of Natural Resources, Energy and Mining: http://www.nccpmw.org/.

[4] Sources included faculty at the Lilongwe University of Agriculture and Natural Resources (LUANAR), government officials in departments of Environmental Affairs, Meteorology, and Climate Change, Agricultural Research Services, and agriculture extensions staff and local community members at Nkhate, Domasi, and Lifuwu irrigation schemes in Chikhwawa, Zomba, and Salima districts, respectively.

3. Scientific Versus Local Perceptions of Climate Variability and Change

Malawi has a sub-tropical climate characterized by a wet (growing) season (November to April) and a dry season (May to October), subdivided into cool and wet (May–August) and hot and dry (September–October) sub-seasons, and mean annual temperatures ranging from 18ºC to 27ºC. Mean annual precipitation ranges from 400 mm in low-lying and rain-shadow areas to over 3,000 mm in high altitude areas, but most (62%) of the counties receive between 790 mm and 1,000 mm (GoM 2011b). Climatic patterns are influenced by terrain/altitude and lake effects, with rainfall increasing with both effects, and regional effects including movement of the Inter Tropical Convergence Zone, ICTZ (McSweeney, New, and Lizcano 2010).[5] However, apparent climate anomalies arising from Malawi's location between two opposing climatic-response regions (eastern equatorial and southern Africa) make predicting Malawi's weather and future climate particularly challenging, especially for precipitation. Inter-annual rainfall variability is generally influenced by the El Niño Southern Oscillation (ENSO) phenomenon by altering the Indian Ocean Sea Surface Temperatures (SST) and by the movement and location of the ICTZ. ENSO impacts on precipitation in Malawi are challenging to predict because of combined regional climate effects from eastern equatorial Africa that generally produce above-average rainfall for El Niño years and from southeastern Africa often bringing below-average rainfall or La Nina conditions (Jury and Mwafulirwa 2002; McSweeney, New, and Lizcano 2010; Nicholson, Klotter, and Chavula 2014). Seasonal climate variability and change, particularly, have important impacts on agricultural production.

Farmer perceptions of past weather variability constitute reality because they affect local understanding of CC and the adoption, or lack thereof, of mitigating or adaptive strategies to enhance the resilience of farming systems and the adaptive capacity of farming households and communities to climate shocks and adverse impacts of CC. Climate variability is not new. However, recent studies show Malawian farmers observing and experiencing weather and climate change, or winds of change, during their lifetimes over the past 3-5 decades (Oxfam 2009), mainly increasing temperatures and declining and more erratic rainfall in amount, timing (onset, frequency, duration, and cessation), intensity, and inter-annual variability (Simelton et al. 2013). Specific reported changes include declining annual rainfall amounts especially at the start and end of the rainy season; a shortening growing season (rains starting later and ending earlier than usual); fewer but more intense rain events; more frequent and intense floods and drought; increasing inter-annual and spatial rainfall variability (including on timing of onset and cessation); increasing numbers of hot or dry days; and longer and hotter summers (ActionAid 2006; Bie, Mkwambisi, and Gomani 2008; Oxfam 2009; Chidanti-Malunga 2011; Kalanda-Joshua et al. 2011; Oyekale and Gedion 2012; Wellard, Kambewa, and Snapp 2012; Simelton et al. 2013; Vincent et al. 2013; Fisher and Snapp 2014; Kakota et al. 2011; Magombo et al. 2012). Reported negative impacts of the perceived changes include declining agricultural productivity, incomes, and food security, and worsening poverty and vulnerability to various other shocks. Many farmers have adopted diverse strategies in response, as illustrated with statistically significant relationships between perceptions of the risk of drought and adoption of improved drought tolerant and early maturity maize varieties (Fisher and Snapp 2014); or preference for early-maturing sweet potato varieties in areas with perceived abbreviated rainy and prolonged dry seasons with high weevil infestations (Chipungu et al. 2012).

[5] Malawi's terrain is dominated by large plateau plains at elevations of 800–1,200 meters, with elevations ranging from 37 meters to a volcanic peak of 3,050 meters on Mulanje Mountain, all over a small land area of 118,483 square kilometers (Saka et al. 2013).

Farmer perceptions of CC generally agree with past (4-5 decades) meteorological and other empirical observations on the increasing trend in temperature, droughts, and climate variability. Temperature records reveal CC already taking place. Mean annual temperatures have increased by 0.9°C between 1960 and 2006 (0.21°C increase per decade), the highest gains during the mid-summer months of December-February and the lowest during the early summer months of September-November (Vincent et al. 2014). In the already warm south, the frequency of hot days is increasing. This is critical because rice and maize are sensitive to hot temperatures over 35°C (95°F), especially during the flowering stage; even a day of extreme heat can cause sterility (Olson et al. 2014). Evaporation has increased in tandem. Evidence also supports local perceptions of increasing frequency and intensity of extreme weather events. The total number of droughts, heavy rains and flood-related disasters increased from 1 in the 1970s to 6, 14, and 19 during the 1980s, 1990s and 2000-2006, respectively (ActionAid 2006; see also GoM 2013c for the period 1949-2008). Of the 40 recorded drought- and flood-related disasters from 1970 to 2006, an average of 1.1 per year, 19 have occurred since 2000 at an accelerated rate of more than three per year. Their impact also increased. The number of people and districts affected has also increased significantly since 1990, with 16 districts classified as flood prone in 2001 compared to 9 before 2001, and 22 having localized flooding in 2003 (Ibid). The two decades leading to 2003 had the longest unbroken period of below-average rainfall (six years) for the period 1900-2003, affirming the increased frequency and intensity of droughts, most severe in southern Malawi (Nicholson, Klotter, and Chavula 2014). Dry spells during the mid-wet season (November-February/March) are particularly important because they occur during the critical maize flouring period and can cause crop failures (Jayanthi et al. 2013). However, no significant long-term trends in extreme weather indices have been detected from daily precipitation data (McSweeney, New, and Lizcano 2010).

Contrary to local perceptions of decreasing rainfall and shrinking rainy seasons (delayed onset and earlier cessation), studies find no significant empirical evidence of persistent long-term trends in total annual rainfall, its timing (onset or cessation), and length in the recent past (4-5 decades), perhaps due to the high inter-annual variability except for some seasonal and geographic variations (McSweeney, New, and Lizcano 2010; IPCC 2001; Ngongondo et al. 2011; Simelton et al. 2013; Nicholson, Klotter, and Chavula 2014; Vincent et al. 2014). Most of the country still had an average annual rainfall from 800 mm to over 1,600 mm between 1901 and 2003, but rainfall amounts have been below normal, especially in northern Malawi with several years of intense drought in the Southern Region during the final two decades (Nicholson, Klotter, and Chavula 2014). Further, there is emerging evidence of higher rainfall variability, especially at the beginning and end of the rainy season. In some Central and Southern Malawi locations, the number of dry days has increased, and mean monthly rainfall declined significantly for March and April in the 1980s and 1990s, but the decreases are virtually compensated for by significant rainfall increases in January (Simelton et al. 2013).[6] January mean rainfall increased by 80 mm at two southern Malawi weather locations, but the number of rainy days did not increase, suggesting a significant increase in rainfall intensity. Analyzing Malawi's rainfall regime, Nicholson, Klotter, and Chavula (2014) found the *agronomic* onset and cessation of rainfall to be stable between 1964/65 and 2008/09.[7] Rainfall starts mid-November

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[6] The Malawi component of the two-country study (including Botswana) used rainfall data from only four meteorological stations: Dedza and Chitedze stations in the center and Chileka and Bvumbwe in the south. Changes are based on comparing averages from the periods 1961/62–1988/89 and 1989/90–2007/08. Ngongondo et al. (2011) also found increases January-February rainfall, but these were statistically insignificant, at some weather stations nationally.

[7] Part of the differences in perception may arise from different descriptions of rainfall onset and cessation. Farmers generally use a meteorological definition (e.g., month rain started) but also apply some agronomic criteria, while scientists

to early December and ends mid-March to early April (105-125 wet season days), except in the northeastern lakeshore region where rains extend to late April or early May (up to 167 wet days), and the southernmost part of Southern Malawi. Simelton et al. (2013) have similar findings on rainfall timing between the periods 1961/62-1988/89 and 1989/90-2007/08. These findings generally agree with farmer perceptions of current meteorological rainfall timing, but reflect no evidence of farmer perceptions of delayed onset (from as early as September in the south) and an earlier end during the past 4-5 decades.

Recent interest in more detailed analysis of past daily weather data suggests higher internal variability and reveals new insights in intra-annual or seasonal and geographic that can help to improve future CC projections. Increasing inter-annual rainfall variability has been observed on national (Ngongondo et al. 2011, period 1960-2006) and local levels (Kalanda-Joshua et al. 2011, for Mulanje district, 1971-2003). Geographically, Nicholson, Klotter, and Chavula (2014) divide Malawi into four climatically homogeneous regions, and show that the two northern regions and the two central and southern ones have distinct rainfall regimes that are opposed to each other. Examining daily rainfall data for 1962–2009, the authors revealed two unexpected features of Malawi's rainfall regime: 1) a region of strong rainfall maximum in the months of December-February along Lake Malawi's western shore, and 2) a short-lived period of reduced precipitation (break) in mid-February, which separates a period (December–February) and rainfall and circulation regime that is dominated by tropical influences from a distinct post-break (March–April) regime dominated by extra-tropical influences.[8] Further, the months of March and April had an unexpectedly dominant contribution to total annual rainfall and variability, particularly in northern Malawi. In the Southern and Central Regions, steadily warming temperatures are leading to higher evapotranspiration and crop water requirements, with higher crop water deficits. Rice is particularly vulnerable because of its water requirements and the limited availability of irrigation water (Olson et al. 2014).

Understanding the sources and consequences of the discrepancies between farmer and scientific perceptions of climate variability and change can enhance adaptation planning and implementation. Causes of the discrepancies include high levels of inter-annual climate variability that complicate both empirical analysis and farmer perceptions of trends. Farmers tend to remember and give more importance to recent timespans and more vivid memories of extreme events and their trends in their adaptation decision making than older and more gradual changes over 4-5 decades, respectively (Marx et al. 2007). Farmers often confuse meteorological (rainfall) with agronomic (soil-moisture) factors, and changes in vulnerability to weather/climate with its impacts (e.g., on yields), and confound changes in sensitivity of farming systems to external factors (e.g., subsidies, information, extension services, economic forces, and poor agricultural and land-use management practices) to weather/climate change (Wellard, Kambewa, and Snapp 2012; Simelton et al. 2013; Magombo et al. 2012). Some farmers mix weather and political factors, e.g., associating good rain years with eras of favored presidents (Simelton et al. 2013). Farmers also generally use external factors, such as the

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use the agronomic onset/cessation based on adequate water availability for plant growth (Kalanda-Joshua et al. 2011; Simelton et al. 2013). The study by Simelton et al. (2013) defines (based on Tadross et al. 2009) onset as the third of three days that have at least 10 mm of rainfall each, but find high inter-annual variability in onset—up to 44 days between at Bvumbwe, Thyolo district, 1961/2-2007/8. For Nicholson, Klotter, and Chavula (2014), onset is when 25 mm of rainfall has accumulated within 10 days if not immediately followed by 10 consecutive dry days (<2 mm), and cessation occurs when three consecutive 10-day periods (dekads) after February 1 have <20 mm.

[8] This break in rainfall appears to coincide with dry spells in February and early March that farmers and empirical evidence (Mwafulirwa 1999; Jayanthi et al. 2013) indicate are the major cause of maize-crop damage and failure in drought-prone areas.

behavior of fauna (e.g., termite density, frog croaking, or flocking/flying behavior of a bird species), changes in plant phenology (e.g., flowering times/intensity of particular plants, high fruit production by mango trees), or environmental conditions or responses (e.g., emergence of the moon during the rainy season, declining soil fertility, reduced stream flow or drying of wells) as traditional indicators for weather and climate forecasting, compounding the discrepancies (Kalanda-Joshua et al. 2011). Further compounding the discrepancies and communication barriers on CC is the lack of clear, unambiguous, generally agreed upon vernacular terms or words to explain climate variability and change. In Malawi's main national language *Chichewa*, a single phrase, *kusintha kwa nyengo,* explains both short- and long-term variability (Simelton et al. 2013).

Failure to reconcile these perceptual discrepancies between scientists and farmers can result in adaptation policies and strategies that are mistargeted, suboptimal, locally inappropriate, or ineffective, and generate obstacles to adaptation or cause maladaptation (Ziervogel et al. 2008; Simelton et al. 201). For instance, farmers in Central and Southern Malawi considered perceived changes in the start/end time of rainfall to be more important in their decision making than total rainfall (Simelton et al. 2013). The perceived increasing trend in unpredictability of onset and dry spells undermined farmers' ability to respond based on past experience. The unpredictability and differential understanding also undermines the ability of extension agents and the meteorological department to advise farmers on the timing of farming practices, while also forcing resource-poor farmers to focus on reactive, short-term coping and adaptation strategies at the expense of proactive or anticipatory strategies that are needed to adapt to future CC. This short-term focus is also almost invariably on adverse impacts of weather variability, undermining farmers' and policy makers' ability to anticipate and exploit potential positive impacts of current and projected future CC. Such discrepancies in understanding also undermine local confidence in official weather/climate information and its utility for farmer decision-making related to weather/climate (Kalanda-Joshua et al. 2011), and, therefore, long-term adaptation planning and strategies. However, adverse impacts of the discrepancies may not be as pronounced because the weather/climate trends that both farmers and scientific evidence agree on (increasing temperatures, dry days/droughts, and variability in rainfall patterns) affect the availability of soil moisture for plant growth, and therefore autonomous agronomic farmer responses are likely to be similar to science-based recommendations. Still, more detailed analysis of the nature and causes of discrepancies between farmer perceptions or indigenous knowledge and scientific knowledge are needed to find creative ways to reconcile or combine the two and enhance communication and use of weather/climate information for planned CC adaption (Kalanda-Joshua et al. 2011). This would ultimately ensure that extension agents, project implementers, policy makers, and scientists "are talking about the same weather, climate, change, and variability, as the farmers they intend to assist" (Simelton et al. 2013). Taking into consideration the context of the smallholder users (usually of significant uncertainty and short-term coping from diverse stresses) and using this to design better and diverse climate-information dissemination approaches can enhance the use of climate and change information (Vogel and O'Brien 2006).

4. Future Projections and Impacts of Climate Change for Malawi

4.1. Projected Climate Change

There is wide variability and therefore uncertainty in future projections of CC derived from various general circulation models (GCMs), especially for precipitation. However, there is more consistency among many GCM-based projections indicating an increasing trend in mean annual temperatures of 1.0ºC - 3.0ºC by 2050, mostly during early summer months of September-November (McSweeney, New, and Lizcano 2010; Saka et al. 2013; Vincent et al. 2014). There is much less agreement on precipitation projections among GCMs in terms of direction and extent of change. In addition to the coarse scale of GCMs, the long, narrow geographic shape and location of the country at the intersection of two or more regional climate regimes contribute to challenges in projecting CC, exacerbated by high local variability due to diverse factors including a varied and complex topography (Ziervogel et al. 2008; Jury and Mwafulirwa 2002; Asfaw et al. 2014; Nicholson, Klotter, and Chavula 2014). Thus, mid-century projections for rainfall in Malawi range from modest decreases (around 25 mm) or no change in some GCMs to increases of up to 400 mm. A study using four GCMs and a mixed model to project CC from 2000 to 2050 generally showed unchanged precipitation levels (models CNRM-CM3 and CSIRO Mark 3) or decreasing precipitation (model ECHAM 5), except in the Northern Region where increases of 50-400 mm were projected by the three GCMs (Saka et al. 2013). One GCM (MICRO 3.2) showed precipitation increases throughout the country, ranging from 200 to 400 mm in the Northern and Central Regions to 50-200 mm for most of the Southern Region. Results from a regional analysis for southern Africa from six downscaled GCMs showed annual rainfall increases for Malawi of more than 45-60 mm (Vincent et al. 2014). These findings further show significant model uncertainly and seasonal variation in precipitation including precipitation decreases in during September-November, but a more consistent projected increase in precipitation during the months of December-February and March-May. Regional analyses from the latest (fifth report) Intergovernmental Panel on Climate Change (IPCC) suggest increasing intensity of extreme events, particularly droughts and hot days for Malawi (Niang et al. 2014), consistent with observed trends in recent decades (ActionAid 2006; Nicholson et al. 2014).

4.2. Impacts of Projected Future Climate Change on Agriculture and Farming Communities

Projected future CC poses a significant threat to Malawi's rain-fed agriculture sector, but it also offers opportunities that are often not addressed in research and policy debates narrowly focused on adverse impacts. The projected higher temperatures and lower precipitation (mainly the south) will cause stress and yield loss to heat and water-stress intolerant crops by increasing evapotranspiration and reducing soil moisture (Simelton et al. 2013), but areas with increased rainfall can see yield gains. However, there is a dearth of research predicting impacts of future CC on agriculture at relevant decision-making scales in Malawi (Gama et al. 2014) and much of Sub-Saharan Africa (Ziervogel et al. 2008; Niang et al. 2014). Still, the few studies show variable predicted CC impacts by crop, agro-ecology and broader context, including yield increases and decreases, and winners and losers (Saka et al. 2013; Gama et al. 2014).

Saka et al. (2013) examined agricultural production and economic impacts of future (2010-2050) CC on maize, cotton, and cassava relative to a baseline based of unchanged climate on four GCMs and the DSSAT crop model under three future scenarios, various CC assumptions and

GDP/development and demographic conditions.[9] Maize-yield projections varied considerably across GCM projections and spatially, from decreases exceeding 25% to increases greater than 25%. Two GSM models contradicted each other, one showing an increase and the other a decrease, of 5-25% nationally. The Northern and Central Regions generally show gains or more optimistic yield predictions than the south, except for pockets including the Shire Highlands and Mwanza and Neno, which showed gains greater than 25%. One GCM predicted a 5-25% yield decline in most of the Northern and Central Regions. The acreage for maize production is projected to remain constant from 2010 to 2050, but a projected yield increase of at least 15% between 2010 and 2030 will disappear or be followed by a small decline. Despite better global maize prices, the study predicts a significant decrease in net exports by 2050 because of increased population growth, underscoring the need for stabilizing future maize productivity and yield. Cotton showed the highest potential for growth under CC and the three model scenarios. With more than a doubling in total production and yield per hectare by 2050 in all three scenarios while largely keeping cotton-dedicated land constant in land-scarce Malawi, and tripling of net exports, cotton could be a major alternative to tobacco as a the key foreign exchange earner. Productivity of cassava and other roots and tubers is projected to increase by nearly 50% in all scenarios but acreage will drop slightly and net exports drastically by 2050 despite world price increases, and imports could be needed. Saka et al. (2013) also find social and health impacts. Under the best-case scenario, they predict a 64% gain in available per capita kilocalories, to 2,800 kilocalories by 2050, and in children's nutrition. This translates into a sharp decline in the number of under-five malnourished children and could enhance the welfare of women by lessening their burdens to ensure good nutrition and health of children. Saka et al. (2013) has suggested that these gains highlight the need for effective population control policies.

The few recent studies confirm the high variability and uncertainty in both CC projections and impacts predictions. A study examining CC impacts on agriculture in Mzimba district (Northern Region Malawi) based on CC projections from downscaled GCMs for the period 2040-2070 confirmed significant temperature increases (1-3°C), but showed modest (but less certain) rainfall decline averaging 1.1% from five GCMs (Gama et al. 2014). It predicts increases of 10%-15% in maize yields. However, impacts are unequally distributed. Over half (56%) of the farmers are predicted to gain in productivity from future CC. Slightly fewer (55%) of those who integrate crops and livestock gain than those (57%) who do not, but the former gained more per hectare. Modest overall gains in per capita incomes (5.2%) and decline in income-based poverty (4%) are also predicted, but the gains are marginally better for integrating than non-integrating farmers—5.3% versus 5.1% for incomes and 6.0% versus 2.0% poverty reduction. Findings call for investment and inclusion of crop-livestock integration in agricultural intensification efforts along with development of heat-tolerant maize varieties and more refined and scaled down analysis of future CC and impacts in different agro-ecological zones to enhance adaptation planning and practice, including exploiting emerging opportunities from future CC impacts.

Other recent studies further illustrate the high variation in future CC impacts geographically and across crops. Modeling impacts of CC on rice production in Malawi, Daccache, Sataya, and Knox

[9] The three scenarios of the future were pessimistic, baseline and optimistic, and the CC assumptions were a GHG scenario of fast economic growth, population peaking midcentury and development of new and efficient technologies, and a balanced use of energy sources.

(2014) also find modest increases in average yields—over 8% and 5% for rain-fed and irrigated rice, respectively for the 2050s. However, high levels of uncertainty (-10% to +20% change in yield) across GCMs and emission scenarios undermine the reliability of findings. Zinyengere et al. (2014) examine local impacts of CC on dryland crops in several sites in Lesotho, Swaziland, and Malawi using statistically downscaled GCMs and the DSSAT crop model, based on common (simulated) agricultural practices for each location. For the Malawi site (Lilongwe), the models predict productivity losses of a third for groundnuts and 5% for maize. Impacts analysis was based on projected mean temperature increase of 1.8 -2.2ºC and minor rainfall change of 1.1% to 2.4% during 2046–2065 compared to a baseline of 1961–2000, using 9 GCMs and a low and high CO2 emission scenario. The ability to test downscaled impacts by alternative agronomic management practices (e.g., early and late planting, common and recommended fertilizer rates for Malawi) is promising for identifying adaptive strategies that can be locally effective.

Research on impacts of future CC on livestock lags way behind (the review failed to find published studies), reflecting underdevelopment of the sub-sector in Malawi, yet selling livestock is commonly mentioned as a coping strategy to climate and other shocks. However, a recent study examining *past* impacts of drought on indigenous livestock production in Central Malawi based on social survey data finds highly significant decreases ($p<0.01$) in goat and pig production with increasing drought incidence (Oyekale 2012). Nearly 39% of respondents ($n=300$ from 21 villages in four sites in Dowa and Lilongwe districts) had been adversely affected by droughts in the preceding five years. Most of them had significantly lower land sizes, farm revenue and credit, and owned a significantly lower number of goats and pigs than those who were not adversely affected by climate shocks. In contrast, farmers who had more land also had significantly higher chicken and pig production. Research on impacts of projected CC on livestock production could enhance adaptation planning. Impacts can be through changes in quantity and quality of available water and feed, incidence and distribution of livestock pests and diseases particularly vector-borne ones, physical impacts (heat, humidity, etc.), and impacts on livestock biodiversity.

A small number of studies have examined broader CC impacts on the national and household economies and their vulnerability to CC, with diverse findings. For instance, using climate, biophysical and economic models, Arndt et al. (2014) found no significant adverse impacts of CC (2007-2050) on economic growth for the next two decades, with predictions of net present value ranging from slightly positive to negative $610 USD. Adverse impacts are likely to become more significant if global emissions remain unabated, including declining agricultural production, and increasing damage to road infrastructure and hydropower generation due to increased frequency of extreme climate events. They argue that the first two decades of predicted positive impacts can buy time to develop innovative CC adaptation policies and strategies, which take a long time to develop (see also Ziervogel et al. 2008). Since agriculture-based coping and adaptation decisions are made mainly at the household level, analysis of CC impacts scaled down to a level that aids such decision-making is important in enhancing the resilience of agricultural systems and adaptive capacity of smallholder farmers.

Diverse social and biophysical factors mediate CC vulnerability, impacts and responses, some of them (on impacts) already discussed earlier (e.g., Saka et al. 2013; Asfaw et al. 2014; Gama et al. 2014). Skjeflo (2013) assesses household vulnerability to climate shocks in Malawi simulated to 2030, and finds that in the case of future climate shocks, rural households with larger farm sizes would benefit from improved prices in maize prices while rural farmers with small landholdings and poor urban households would be particularly vulnerable to CC because much of their incomes is used on food. Analysis of factors shaping vulnerability of farming households to climate-related income shocks in Lilongwe and Dowa districts finds that being in a male-headed household, located in Lilongwe, and being an adult female with secondary education, were associated with significantly higher levels of vulnerability; while attainment of secondary education among adult males, use of improved soybean or cowpea varieties, access to irrigation, and shorter distance to village markets were associated with lower vulnerability (Oyekale and Gedion 2012). Drought was the major driver of climate-related income shocks (83% of respondents, n=300), as in most parts of Malawi. These differentiated vulnerabilities and impacts underscore the need for developing and/or ensuring access to a basket of best-bet adaptation strategies for particular agro-ecologies and household characteristics.

5. Adaptation Policies and Strategies to Climate Variability and Change in Malawi Agriculture

5.1. Climate Change Policies and Strategies

Malawi has taken concerted policy and institutional responses to CC. However, these efforts have largely been in reaction to national reporting and planning obligations under the UN Framework Convention on Climate Change (UNFCCC), driven and funded by donor agencies, and remain disjointed across key sectors and inadequate. However, CC policy processes have generally been participatory, incorporating diverse government agencies, NGOs, academics, and private sector representatives, though community participation has been limited (Chinsinga, Chasukwa, and Naess 2012; Kosamu 2013). Further, the policy processes are increasingly more proactive and moving towards mainstreaming of CC in development sectors, including integrating CC concerns as one of nine priorities in Malawi's medium-term economic development plan, the second Malawi Growth and Development Strategy (MGDS II) for 2011-2016, and into its national agricultural development priorities and plan under the Agriculture Sector Wide Approach, ASWAp (GoM 2011a); finalizing a draft National Climate Change Policy in 2014 which awaits Cabinet approval; and developing various policy related instruments.[10] Such instruments include Malawi's Strategy for Climate Change Learning to "strengthen human resources and skills development for the advancement of green, low emission and climate resilient development" by 2030 (GoM 2013b); its National Environment and Climate Change Communication Strategy (NEECS); the 2013 Malawi's Strategy on Climate Change Learning establishing; and establishing the National Climate Action Intelligence (CAI) Database to document main players in CC, what they are doing, and where. Malawi has also developed a $954.5 million USD National Climate Change Investment Plan (NCCIP) for 2013-18. The NCCIP is designed "to increase and coordinate climate change investments in Malawi" in 22 programs under four major thematic areas: adaptation (48.2% of investment), mitigation (19.7%), climate change research, technology development and transfer (19%), and capacity development in CC (13.1%) (GoM 2013a).

[10] The other eight MDGS II priorities are agriculture and food security; energy, industrial development, mining and tourism; transport infrastructure, and development of the Nsanje World Inland Port; education science and technology; public health, sanitation, malaria, and HIV/Aids management; integrated rural development; the Green Belt irrigation and water development; child development, youth development and empowerment; and natural resources and environmental management.

Within broader provision of the MGDS II, the 2006 Malawi National Adaptation Plan of Action (NAPA) and the ASWAp remain the two main policy guides on agriculture and climate change. The NAPA, prepared under UNFCCC auspices, identified national priorities to address Malawi's urgent and immediate adaptation needs. [11] The five priorities were in the form of project concepts, including improving agricultural production, which were valued at $22.43 USD, but remained unfunded (with one exception). The other four priorities were enhancing community resilience, restoring forests, strengthening preparedness for floods and droughts, and boosting climate monitoring.

The ASWAp contains Malawi's current core but brief and underdeveloped policy statement on CC and agriculture, focusing primarily on enhancing resilience of agricultural systems to climate change risks and impacts with an extreme-event focus on drought and floods, but also includes some (combined) CC mitigation strategies. The main strategies focus on mitigating impacts of drought and floods mainly through improvement of drought and flood early warning systems including for associated pests and diseases, and adopting technologies against drought. The latter include promoting adoption of drought-tolerant varieties and management practices, tree (including fruit) planting on fragile land and Jatropha trees for production of biodiesel to mitigate greenhouse gas emissions, soil and water conservation strategies, including conservation agriculture and rehabilitation of degraded agricultural land, irrigation dams and water harvesting and storage strategies, protection of fish breeding grounds from drought/flood, and development of drought preparedness strategies and impact (crop) assessment (GoM 2011a). However, CC is poorly integrated within the core ASWAp priorities.[12]

A national agricultural policy under development (advanced draft) treats CC adaptation and mitigation in agriculture more holistically, providing for demand-driven and gender responsive agricultural research, collaboration, participatory approaches and capacity strengthening. However, it suffers similar challenges of treating CC adaptation and mitigation as a policy add-on hardly integrated into the core thematic areas and without budgetary commitment to CC provisions (Mwase et al. 2013). Even a study (policy note) on research capacity for operationalizing the ASWAp (Mapila et al. 2012), does not mention climate change at all. Similarly, the proposed (draft) climate change policy is much more comprehensive on agriculture and addresses some of the challenges associated with lack of a comprehensive, coordinated policy approach to CC. Challenges include the many still uncoordinated and overly broad sector policies, which undermine the ability to address complex CC needs; poor project, program and cross-sector coordination and leading to duplication and contradictions among activities, projects, sectors and donors; limited awareness of CC impacts and responses; low, poorly coordinated and unpredictable investment in CC adaptation; limited political and institutional commitment to CC; poor institutional capacity and coordination (including conflicts) in CC governance; limited capacity and focus on reducing community vulnerability to CC ; and underfunding and low commitment to research and its integration into CC policies and adaptation interventions (GoM 2011d; Chinsinga, Chasukwa, and Naess 2012; Kosamu 2013;

[11] Malawi signed the United Nations Framework Convention on Climate Change (UNFCCC) on June 10, 1992, and ratified it on April 21, 1994, followed by accession to the Kyoto Protocol in 2001.
[12] CC strategies are relatively well linked to the food security and risk management ASWAp focal areas, but get a cursory mention within the sustainable land and water management focus, and none in the agri-business and market development focal area and in the two support services of institutional strengthening and capacity building (including research) and technology generation and dissemination, or the two ASWAp cross-cutting issues of HIV/AIDS and gender inequity issues.

Mwase et al. 2013). The fragmented treatment of CC adaptation, mitigation, and disaster risk management—rather than an integrated approach that harnesses their synergistic benefits both within agriculture and broader promotion of a green economy—remains a challenge (GoM 2011d). Hardly any of the studies addresses community-based adaptation, despite its agreed importance as a major strategy to alleviate poverty in Africa (Niang et al. 2014).

Heavy donor dependency and some government policies also have impacts on CC adaptation. One consequence of the dependency is external influences on policy priorities, which tend to make adaptation in Malawi supply-driven rather than demand-driven (Chinsinga, Chasukwa, and Naess 2012). According to Chinsinga, Chasukwa, and Naess (2012), recent CC debates have tilted towards carbon-sequestration projects (particularly Reducing Emissions from Deforestation and Forest Degradation, REDD+) whose benefits for Malawi remain fleeting, at the expense of policy responses linking climate smart strategies into sustainable agricultural and broader development (see also Yocum 2013). Brooks (2014) finds that top down *new green revolution* strategies ostensibly promoting both agricultural intensification (using hybrid maize and crop diversification) and adaptation to CC in Malawi and Kenya fail to adequately address realities of poor smallholder farmers and produce more conflicts that synergies between the two goals. In particular, "a convergence of interests between governments, donors and seed companies, combined with a historical preference for and dependence on maize as the primary staple, has led to a narrowing of options for smallholder farmers, undermining the development of adaptive capacities in the longer term" (Brooks 2014; see also ActionAid 2006).

Malawi's Fertilizer Input Subsidy Program (FISP) is the largest and highest-priority single policy strategy for both agricultural and broader economic development in Malawi, yet hardly any research has been done to explicitly examine its impacts on resilience of agricultural systems to CC and the adaptive capacity of farming households or communities to CC.[13] A well-meaning program that has since 2005/6 provided much needed improved seed and fertilizer to poor (more than half or all) smallholder farming households at highly subsidized prices (64%-95% between 2005/6 and 2010/11), and has on balance achieved its goals of increasing agricultural productivity (producing food surpluses for several years), enhancing rural livelihoods and promoting food security at national level (Pauw and Thurlow 2014). However, the FISP attracts increasing levels of doubt involving its net costs (including opportunity costs) and benefits at multiple scales, subsidy targeting and benefit distributional effects issues, input distribution efficiency, and its politicization, broader socio-ecological impacts, and financial sustainability given the increasing cost of the subsidies. Early analysis of FISP performance shows mixed impacts on farm household dynamics (including incomes and gender dynamics), farm-level agronomic and system-wide agricultural impacts, and broader politico-economic ones, some of which have implications for CC adaptation.

Dramatic increases in maize production nationally and modest but significant pro-poor increases in income (but not assets) associated with FISP are tempered by mixed and unequal marginal returns on fertilizer use and income/benefit distribution effects at household level with better-off households benefitting more than poorer ones (Arndt, Pauw, Thurlow 2013; Lunduka, Ricker-Gilbert, and Fisher 2013; Pauw and Thurlow 2014). Some studies show cropping-system simplification due to over-emphasis on maize (Action Aid 2006; Brooks 2014) or to causal links of participation in FISP to reduced crop diversification (Chibwana, Fisher, and Shively 2012;

[13] FISP takes more than 70% of the agriculture ministry budget (IFAD 2011).

Kankwamba, Mapila, and Pauw 2012) contrasted with evidence of higher crop diversification among beneficiaries than non-beneficiaries attributed to non-beneficiaries growing more maize to qualify for the subsidy and/or agricultural intensification and higher yields enabled by the subsidy freeing up land for other crops, though there is need to more rigorously isolate non-FISP contribution (Pauw and Thurlow 2014).[14] Holden and Lunduka (2010) found increasing maize intensification between 2006 and 2009 associated with a decrease in total maize area from 0.37 million to 0.64 million hectares. Some findings suggest that FISP can contribute to yield instability under climate variability. Simelton et al. (2013) attribute increases in both maize yields and yield variability (while rainfall variability remained relatively constant) between 1990 and 2006 partly to increasing use of hybrids with uncertain performance under weather and climate extremes compared to the indigenous varieties they displaced. Further, FISP's sheer size and the government's preoccupation with it diverts resources, including research and extension effort, away from promotion a broader range of adaptation strategies, including those with longer-term benefits—e.g., sustainable land management, intercropping, conservation agriculture, or agroforestry (Chinsinga, Chasukwa, and Naess 2012; Pauw and Thurlow 2014). Broader land use impacts of relevance to CC adaptation also vary. For instance, subsidies on tobacco increase demand for trees exacerbating forest degradation and deforestation—undermining CC adaptation and mitigation—while maize intensification (Lunduka, Ricker-Gilbert, and Fisher 2013) and income gains can modestly reduce agricultural expansion into forests and dependence of forest products for cash, thereby reducing deforestation rates (Fisher and Shively 2007).

In addition to these largely unintended consequences of the FISP, recent studies also show how the program falls short on several of its intended outcomes, including contributions to climate-resilient farming systems and adaptive farming communities. A study of the impacts of fertilizer subsidy programs on total fertilizer use in Kenya, Malawi, and Zambia, Jayne et al. (2013) shows that conventional benefit-cost (BC) analyses, which generally do not account for effects of crowding out of commercial fertilizer and the illicit diversion of subsidy fertilizers before they reach intended beneficiaries (at least 33% in recent assessments), may grossly "overestimate the contribution of the subsidy programs to national fertilizer use by 67.3% in the case of Malawi, by 61.6% for Zambia, and by 138.0% for Kenya" (page 687). Further, marginal gains in value for the maize produced under such programs are much lower than their costs in most years, unless maize prices are assumed to be inordinately high. Such high maize prices are unrealistic given anticipated (and intended) reductions in maize retail prices because of such subsidies. This is so even when such subsidy-driven maize-price reductions are very modest, 1.2–2.5% in Malawi and 8–2.8% in Zambia on average from 2000–2001 to 2011–2012 (Ricker-Gilbert et al. 2013). Significantly, in a climate-change context, the ensuing deficit between hypothesized decreases in retail maize prices that are meant to benefit urban consumers and the rural poor who are generally net food buyers, adds to the ways that Malawi's FISP may undermine or under-deliver on the program's contribution to the resilience of farming systems and adaptive capacity of smallholder farmers to climate variability and change. While such contributions could be increased by instituting more effective targeting and prevention of diversion of subsidy fertilizers, broadening soil fertility management approaches beyond fertilizer-only approaches may contribute more to climate-smart agriculture and adaptive farming communities. In sum, the limited literature on FISP shows that the program can have significant but diverse impacts on CC adaptation, and a more detailed and spatially explicit analysis is needed, including inclusion of its effects as mediating variables in broader analyses of CC impacts, in order to mitigate its negative and enhance its positive impacts on CC adaptation.

[14] Chibwana, Fisher, and Shively (2012) found a 16% increase in land allocated to maize among FISP participants.

Studies and reports on institutional responses to CC suggest improving, if not yet significant, coordination and communication among national-level government agencies in key climate-vulnerable sectors and NGOs, academic institutions, donors agencies and the private sector, but little coordination and communication between them and local institutions and communities, as well as between adaptation policy intentions (and rhetoric) or strategies and local adaptation implementation and actions, and between interventions (Kosamu 2013; GoM 2011d, 2013c). This coordination has yet to extend to harmonization of policies across relevant sectors with respect to CC. Locally, strategies proposed by experts often fail to adequately address or reflect local concerns and livelihood needs, including incorporation of indigenous local knowledge and strategies, and therefore undermine the success of adaptation strategies (Kosamu 2013; see also GoM 2011d; Kalanda-Joshua et al. 2011). National coordination is facilitated by a CC-response super institutional structure that elevates CC as a development (not just environmental) concern, starting with its designation as one of nine development priorities in MGDS II under the ultimate responsibility of the Ministry of Finance and Economic Development while the Department of Environmental Affairs serves as the coordinating agency and UNFCCC contact agency. National technical and policy structures are in place: the ministerial-level National Steering Committee on Climate Change, chaired by the finance ministry providing policy guidance, and the department-level National Technical Committee on Climate Change (includes academia, NGOs, and the private sector) bringing technical input, and the Government/Donor Working Group on Climate Change helping to mobilize and coordinate resources, and the Civil Society Network on Climate Change for information sharing, advocacy, implementation and monitoring of CC actions among NGOS working on CC and disaster risk reduction (GoM 2013c; Kosamu 2013).[15] Other levels of coordination are provided by a Youth Network on Climate Change to advance awareness and mobilize the youth on CC, and the Journalists Association on Environment and Climate Change to promote awareness. Two major national programs, the National Climate Change Program (2009–2016, supported by Norway, DFID, United Nations Development Program [UNDP] and Japan), and The Africa Adaptation Program in Malawi (Japanese support) have been instrumental in supporting such coordination, along with resource mobilization for CC adaptation and mitigation including through the National Climate Change Investment Plan; facilitating the formulation, implementation, and evaluation of CC policy, strategies, and tools; catalyzing a shift from reactive to proactive adaptation especially in agriculture and land management; coordinating and mainstreaming climate change into development policies, plans, and projects; enhancing generation and access to climate/CC data for decision making, providing technical capacity, and building human and institutional capacity to handle CC responses; and beginning to implement adaptation and mitigation activities. CC adaptation in agriculture is likely to benefit from these institutional arrangements.

A recently developed Climate Intelligence Action (CAI) computer database of who is doing what and where on CC in Malawi (1993-2012) shows a wide diversity of institutional stakeholders dominated by government and non-state agencies (GoM 2013c).[16] It further shows a significant increase in direct CC actions (projects/programs) and funding between introduction of the NAPA

[15] Although it has created some institutional conflicts particularly between the finance and the environment and natural resources ministries, the elevation of CC into a development issue to be integrated into national development planning is a generally positive move for mainstreaming adaptation.

[16] Of 225 institutional actors on CC activities identified in 22 districts, government agencies constituted 33%, non-state actors (foreign government entities, UN entities and donor agencies) 27%, civil society and NGOs (23%), the private sector (7%) and academia (5%) (GoM 2013c).

in 2006 and 2012, dominated by a few major actions, and geographically concentrated in the Southern Region (50% compared to 22% each for the Northern and Central Regions) and in a few districts particularly vulnerable to extreme weather events (Karonga, Chikwawa, Zomba, Nsanje and Balaka).[17] Thematically, actions on adaptation dominate (40%) compared to mitigation (28%), and policy, technology transfer, REDD+ and Clean Development Mechanisms (CDMs) at less than 3% of actions. While direct CC projects are overwhelmingly funded by international foreign governments and donor agencies, the major lead funders (by number of projects) are the Japanese International Development Agency (JICA, 17 projects), the Global Environment Facility Trust Fund (11 projects), and Norwegian Government (6 projects), while locally the Malawi Environmental Endowment Trust has funded the most projects, 9 (GoM 2013c). Of 149 direct CC activities identified, 19% were in agriculture and 12% were in the vulnerability and risk management sectors, while the bulk (43%) were in environment, lands and natural resources sectors. Health, tourism/wildlife and gender/youth sectors were least represented at 3% in total. For actions/projects that had funding information provided in the database, the scope of actions ranged widely from a small climate change workshop (an event) costing just over $1,500 USD to projects/programs running up to 10 years and a budget of $120 million USD, with the top 13 projects (>$10 million USD) funded mainly by the World Bank, the European Union, the British government, the Global Environmental Facility, and Norwegian government, several of them in agriculture. There appears to be a promising trend among the major projects of moving from short-term (1-5 year) to longer-term projects/programs.

In agriculture, major direct adaptation actions include the Sustainable Agricultural Production Program (SAPP) funded by the International Fund for Agricultural Development (IFAD, $51.1 million USD total, 2011-2020); Irrigation, Rural Livelihoods and Agricultural Development Project (IRLAD, lead funder World Bank, total cost $65.2 million USD, 11 districts, 2005-2013); Agriculture Development Program Support to Sustainable Land Management (GEF, $36.4 million USD); Agriculture Development Program - Input Subsidy program (DfID, $6.75 million USD; and the Climate Adaptation for Rural Livelihoods and Agriculture (CARLA, 2012-2015, $3 million USD, target 30,000 beneficiaries). CARLA implements integrated CC adaptation strategies that support production and rural livelihoods and enhance national and district agencies' capacity to support community-based adaptation to CC focusing on three vulnerable districts of Karonga, Dedza, and Chikwawa. SAPP is particularly promising for its scope and goal of promoting a viable and sustainable smallholder agricultural sector targeting 200,000 farm households in six districts by "promoting GAPs (good agricultural practices), which are more resilient to climatic extremes, especially droughts, and climate change mitigation through carbon sequestration in soil organic matter" (IFAD 2011). It also commendably includes a participatory adaptive research and knowledge management component ($5.4 million USD) to develop and test promising GAPs on-farm and off-farm (including conservation agriculture (CA), crop storage, and research and soil fertility management to improve FISP effectiveness, and to assess GAP adoption behavior and effective extension methods. IRLAD has helped to improve the resilience of maize and rice farming systems along with doubling of productivity and 60% increase in farm incomes thereby enhancing the adaptive capacity of more than 280,000 households (1.5 million people) in 11 districts. IRLAD further promoted improved seed varieties, sustainable land management practices, crop diversification, high density planting, and intercropping, and enhanced irrigated agriculture (16 small scale schemes covering 2,000 hectares and four old larger schemes rehabilitated), thereby reducing

[17] Some of the increase may be relabeling of projections whose original intent was not, or was only indirectly, related to climate change.

farmer risks from rained agriculture (World Bank 2013). Ongoing development of Malawi's ambitious Green Belt Initiative—another major agricultural/economic policy strategy to increase agricultural productivity, incomes, agricultural processing and trade, and ensure climate-resilient agriculture by expanding irrigated land initially from 70,000 to 200,000 hectares—also holds promise for climate change adaptation. These, and other elements of other integrated development projects including the newly funded Shire River Basin Management Program (Phase-I, 2014-2018, lead funder World Bank, total cost $136 million USD) focusing on enhanced land and water management for ecosystem and livelihood benefits, indicate increased but still insufficient number of adaptation implementation projects. The Norwegian government supports the biggest agriculture and CC research project, the Capacity Building for Managing Climate Change in Malawi, CABMACC ($13.073 million USD, 2012-2017). It seeks to enhance university capacity and that of national stakeholders towards improvement of livelihoods and food security via climate-smart strategies (GoM 2013d).

Ultimately, despite (more accurately because of) the dependence on donors, but notwithstanding the many extant challenges, preparation and a confluence of favorable factors appear to have brought Malawi to the cusp of a significant positive shift in its policy, strategic and tactical response to CC and variability. This shift includes the foundation for a transition from awareness to action, from disjointed to harmonized CC policies, from national policy and planning to local implementation and benefits, from short-term reactive to proactive adaptation, and according to Ziervogel et al. (2008) the changeover from "simply responding to UNFCCC and GEF reporting requirements and to begin engaging in the dynamics of future climates and their implications." In fact, the UNFCCC and other agencies often put Malawi up as an exemplar among the Least Developed Countries (LDCs) for its policy and institutional responses to CC and underlying participatory processes. Preparations include creation of technical working groups, pending national climate change policy which also enhances adaptation policy in agriculture, identification of priority adaptation investment opportunities for 2013-2018), formulation of a CC communications strategy, and publication of adaptation and mitigation best practices (GoM 2012) to promote their wider adoption and scaling up. Used and updated regularly, The CAI database can help to enhance coordination of CC adaptation interventions at multiple scales, direct and analyze investment trends, and monitor policy and strategy implementation. Malawi has also started (2014) the UNFCCC-driven process of transitioning from the NAPA and its focus on *urgent and immediate* adaptation needs to the National Adaptation Plan (NAP) emphasizing medium- to long-term adaptation planning and project implementation. Political will is also strong and donor agencies are generally willing to support adaptation planning and programs as the CAI database illustrates. Major agricultural programs, especially the FISP and Greenbelt Initiative, offer opportunities to enhance CC adaptation components. However, on top of challenges mentioned earlier, the review reveals neglect of the private sector in agricultural policies on CC. Although agriculture is dominated by the smallholder sector and poverty reduction is an overriding goal, CC policies and strategies that include both allow for a more coherent and holistic approach and exploit synergies that would enhance the sector's resilience to CC and the farming community's adaptive capacity. For instance, some of the technologies needed are produced by the private sector.

5.2. Adaptation Responses and Strategies to Climate Variability and Change

Climate-related responses in Malawi's agriculture and other natural resources sectors are currently dominated by coping strategies or autonomous local adaptation strategies to past and contemporaneous climate variability, with low but increasing implementation of planned or anticipatory adaptation. Autonomous strategies are primarily reactive short-term responses to climate shocks and risk for survival or for meeting present and urgent needs, but they may include interventions that also have (incidental) longer-term agro-ecological benefits that enhance system resilience and farmer adaptive capacity to CC, whereas "planned" (Parry 2007) or "anticipatory" adaptation strategies (IPCC 2001) are proactive, designed, and long-term responses based on knowledge and projections of future climate change. A significant and growing number of studies have documented current and past adoption of diverse mixes of indigenous and modern science-based strategies in response to perceived climate and environmental variability. However, their mainstreaming or implementation as policy-driven interventions remains limited (Stringer et al. 2010). Their potential long-term effectiveness as "climate smart" strategies under particular conditions, and factors that influence their adoption, are relatively unknown but the subject of nascent research interest (e.g., Snapp et al. 2002; Kerr et al. 2007; Magombo et al. 2012; Nordhagen and Pascual 2013; Saka et al. 2013; Snapp et al. 2013; Asfaw et al. 2014; Fisher and Snapp 2014; Gama et al. 2014; Ngwira, Aune, and Thierfelder 2014; Ollenburger and Snapp 2014; Thierfelder et al. 2013; Thierfelder, Matemba-Mutasa, and L. Rusinamhodzi 2015).

Individual smallholder farmers and communities in Malawi have adopted many indigenous autonomous adaptation strategies to climate variability and change and woven them into complex livelihood approaches. These strategies can form the basis for anticipatory adaption to future CC. Smallholder farmers use indigenous coping and adaptive strategies to mitigate adverse impacts of droughts and erratic rainfall, but often in combination with soil fertility management and improvement (Asfaw et al. 2014). Strategies include changing or diversifying crop and livestock varieties, altering cropping systems and technologies, changing farming practices, altering broader land-use practices, crisis responses, and adopting off-farm interventions. For crop type or variety diversification, farmers often adopt higher-yielding, early-maturing, and drought-, water stress- and heat-tolerant varieties (e.g., for maize, rice, cassava, and potatoes), and growing more drought resistant crops, such as cassava, sweet potatoes, soya, pigeon peas, and cotton (Phiri and Saka 2008; Ziervogel et al. 2008; Wellard, Kambewa, and Snapp 2012; Chipungu et al. 2012; Mhango, Snapp, and Kanyama-Phiri 2013). Strategies involving changing farming practices include increasing use of organic fertilizers (e.g., compost, animal manure, legumes), and changing planting time (earlier or later), spacing and intensity planting (Ziervogel et al. 2008; Magombo et al. 2012; Wellard, Kambewa, and Snapp 2012). Many farmers who alter their farming systems and technologies in response to CC have increased use of intercropping, adopted small-scale irrigation and wetland (*dambo*) farming, increased residual moisture management to enhance crop-use efficiency, and integrated livestock into farming systems (Stringer et al. 2009; Stringer et al. 2010; Chidanti-Malunga 2011; Magombo et al. 2012; Wellard, Kambewa, and Snapp 2012). Land use and management responses mainly target soil/water conservation and fertility management. They include constructing contour ridges and planting trees on farm or integrated into agroforestry systems. The multiple benefits they generate off-farm contribute to protecting watersheds and soils, harvesting rainwater, and stopping/preventing bush fires (Ziervogel et al. 2008; Kalanda-Joshua et al. 2011; Wellard, Kambewa, and Snapp 2012; Mwase et al. 2013; Vincent et al. 2013; Kakota et al. 2011).

Many of these strategies reveal rich indigenous knowledge and decades of innovation that can be combined with scientific knowledge to enhance CC resilience and adaptive capacity (Chipungu et al. 2012; Magombo et al. 2012). For instance, smallholder farmers in Chikhwawa district used 29 different combinations of adaptive strategies to climate variability (Magombo et al. 2012). Farmers in seven districts in Northern and Southern Malawi used complex indigenous classification systems for potatoes to identify 268 predominantly indigenous potato varieties (Chipungu et al. 2012). They also have an indigenous germplasm custodial system, and 64 of 122 farmers interviewed played this custodial role for local potato varieties. Early maturity is now a critical potato trait (68% of respondent) selected for, and farmers cite increasingly truncated rainy and prolonged dry seasons as the main driver, along with the need to reduce exposure to a growing weevil infestation. Long post-harvest storage life and traits that allow relay harvesting are also preferred. The long-standing practice of retaining and replanting nitrogen-fixing trees, particularly *Faidherbia albida* in maize fields for soil moisture conservation and fertility improvement, is another example of a valuable strategy for climate variability and change adaptation (Garrity et al. 2010; Wellard, Kambewa, and Snapp 2012). Mixed with small doses of fertilizer, this practice has more than doubled maize yields and enhanced incomes in Malawi and Zambia (Garrity et al. 2010).

With facilitation from government extension agents, research agencies, NGOs and private sector agents, many farmers have also adopted science-based interventions in response to climate variability and risk (Fisher and Snapp 2014). However, many factors undermine widespread adoption, including poverty, poor access to credit, inadequate information and fragmented technology support, poor availability and access to necessary farm inputs (e.g., tools, improved seed including for legumes, herbicides, fertilizers), labor shortages, poor markets, under-resourced extension, dependency on free or subsidized inputs, and inadequate strategic planning to integrate climate-smart technologies for improved productivity in major programs such as FISP (Kerr et al. 2007; IFAD 2011; Asfaw et al. 2014; Mhango, Snapp, and Kanyama-Phiri 2013; Nordhagen and Pascual 2013). Modern strategies involve improved crop and livestock varieties and types, inorganic fertilizers, and tested agronomic systems, practices, and basic technologies. The Department of Agricultural Research Services (DARS) and private seed companies have produced and released many climate smart seed varieties, cropping systems, and cultural practices for maize and minor legumes, rice, legumes, fruits and livestock, particularly drought/heat tolerant and early maturity varieties and systems/practices suited to drought-prone and low-medium rainfall areas (400-1,000 mm).[18] Benefits can be high. For instance, Khataza (2010) estimates national economic benefits for Malawi consumers and producers from adopting improved moisture-stress-tolerant and early maturing varieties at $379 million USD for maize and $11 million USD for cassava in total discounted production gains between 1980 and 2008.

A number of climate-smart "best bet" innovations already tested or currently under testing on farmers' fields hold promise for adaptation to CC. The government published some practices in in a recent guide: *Climate Change Adaptation and Mitigation Best Practices in Malawi* (GoM 2012). The use of participatory research such as the mother-baby trial approach farmer field schools, which combine collective research and farmer learning from/on communal plots demonstrating a range of technologies with individual application of preferred ones, has been effective in promoting such technologies (Snapp 1999, 2002; Snapp et al. 2002). Diversified maize-based cropping systems integrating annual crops and (often nitrogen-fixing) perennials or semi-perennials offer both short-term soil improvement and longer-term agro-ecological benefits for sustainable production, as well as wood for fuel and other uses. Maize-based intercropping and rotation systems integrating multi-purpose, semi-perennial legumes such as pigeon peas are particularly promising. Both the annual crops (mainly maize) and the semi-perennials provide enhanced and relatively immediate benefits of food and nutrition improvement, fodder and cash while the deep-rooted pigeon peas further

[18] Most of these are published in *A Catalogue of Agricultural Technologies* (GoM 2011b) but others can be found in DARS station reports.

provide the biomass and agro-ecological benefits of improved soil fertility (including 10-plus months of nitrogen fixation and phosphorus solubilization in Malawi's predominantly nitrogen and phosphorus deficient soils), plant water-use efficiency, soil erosion minimization, soil carbon-stock building, maize-yield stabilization and market diversity (Bezner Kerr, Berti, and Shumba 2011; Mhango, Snapp, and Kanyama-Phiri 2013; Snapp et al. 2013). In a study in Central Malawi, pigeon pea/maize systems at least doubled maize yields relative to a maize monocrop control (from 1,750 kg/ha to 3,500 kg/ha for the maize-pigeon pea intercrop and up to 4,400 kg/ha for the pigeon pea/maize-rotation) after 10 years of implementation with low fertilizer application (Ollenburger and Snapp 2014). Mhango, Snapp, and Kanyama-Phiri (2013) showed a 58% maize-yield increase for a pigeon pea/maize intercrop and a 60% gain for a doubled-up legume (groundnuts and pigeon pea)/maize intercrop in northern Malawi. Significantly for adaptation, these diversified maize/pigeon pea systems can reduce maize-yield variability (Snapp et al. 2010) and the risk of crop failure under increasing temperatures (Ollenburger and Snapp 2014). Studies suggest that research, policies and extension efforts should focus on addressing obstacles to the adoption (including livestock damage), finding more effective methods for scaling up the maize/legume systems, and research on participatory decision-making and modeling, and development of climate-resilient germplasm and agronomic practices (e.g., Kerr et al. 2007; Fisher and Snapp 2014).

Despite the growing knowledge on agricultural technologies and practices that have potential for climate-proofing Malawian smallholder agriculture, little is known about their potential effectiveness under projected future CC scenarios. In one study exception, Asfaw et al. (2014) used national survey and diverse biophysical data to examine the relative effectiveness of, and factors (including recent climate variability and shifts) that influence the choice of, modern inputs (inorganic fertilizers and improved seed) and four commonly promoted sustainable land management (SLM) adaptation strategies: maize-legume intercropping, soil and water conservation (SWC), tree planting, and application of organic fertilizers. They found that adoption of both modern and SLM strategies consistently improved maize yields overall. However, farmers exposed to higher climate variability or biophysical sensitivity and risk selected and produced significantly higher maize yields from the SLM strategies while reducing use of costly chemical fertilizers, which have uncertain risk-reduction benefits under climate variability. Farmers in low climate-risk areas tend to choose and obtain higher maize yields from modern strategies. Another recent study predicts not only gains in maize yield (10%-15%) in per capita incomes and poverty reduction among most farmers in Mzimba district under projected 2010-2070 climate, but also that farmers using integrated maize/livestock systems will initially gain more, though the gains will be lost at the end of this period due to rainfall decline if adequate anticipatory adaptive strategies are not implemented now (Gama et al. 2014). Nationwide crop modeling (DSSAT) under several future (2010-2050) climate, demographic, and economic scenarios show considerable potential for crop diversification gains especially for cassava and other tubers and cotton, while maize is projected to register modest gains in the first 20 years, which then flatten in both yield and acreage before declining towards the end of the period (Saka et al. 2013). Polices that increase the productivity and resilience of these crops to projected CC will bear dividends and mitigate adverse effects.

Conservation agriculture (CA), an ensemble of practices based on principles of no or minimum tillage, permanent organic soil cover including mulching, and diversified crop rotations, is increasingly promoted (including via ASWAp) as a near-ideal CC adaptation solution for Malawi by the government NGOs, donors, and researchers, although the debate on its value is yet to be settled and adoption of formal CA remains very low (Ngwira, Aune, and Mkwinda et al. 2012). Touted multiple benefits of improved soil fertility and yields, reduced labor requirements, weed control, soil and water conservation, and erosion reduction make CA increasingly popular in Sub-Saharan Africa (Giller et al. 2009; Ngwira, Aune, and Mkwinda 2012; Richards et al. 2014). Still, crop modeling can be used as a tool to screen CA strategies for CC adaptation. Using the DSSAT model and the no-till and crop-residue retention CA practices and future (2010-2030) CC scenarios, Ngwira, Aune, and Thierfelder (2014) show significant gains in maize yields and water-use efficiency of 451 kg ha^{-1} of maize and 1.62 kg of maize per millimeter of rainfall, respectively, for a maize-cowpea rotation compared to traditional tillage at medium latitude sites in Lilongwe. The two CA strategies also stabilized yields and were less likely to produce below-recommendation yields than the standard tillage option, underscoring their potential value for CC adaptation. Thierfelder, Matemba-Mutasa, and L. Rusinamhodzi (2015) also generally show yield gains with CA practices in Malawi, Mozambique, Zambia, and Zimbabwe. Gains were up to 1,172 kg ha^{-1} and without a maize-yield penalty for a maize-legume (cowpeas or pigeon peas) intercrop with no-tillage but residue retention compared with sole maize with residue retention and no tillage. In target communities in Central and Southern Malawi, conservation agriculture increased rainwater infiltration by 24–40%, increased maize yield up to two-fold with the greatest benefits starting during the fifth growing season, compared to conventional tillage crops, and was found to be suitable under diverse soil and rainfall conditions so long as fertilizer, herbicides, and labor are adequate (Thierfelder et al. 2013). However, CA remains controversial given its mixed and sometimes conflicting results relative to expected benefits under African conditions, such as limited access to herbicides and inorganic fertilizers. According to Giller et al. (2009), "concerns include decreased yields often observed with CA, increased labor requirements when herbicides are not used, an important gender shift of the labor burden to women and a lack of mulch due to poor productivity and due to the priority given to feeding of livestock with crop residues." Still, the latest Inter-governmental Panel on Climate Change report assigns *high confidence* to CA as having "good potential to both bolster food production and enable better management of climate risks" (Niang et al. 2014). For Malawi, Food and Agriculture Organization (FAO) estimates only 65,000 hectares or 1.7% of arable land are under CA systems in 2013 (Richards et al. 2014).

Studies also suggest a need to better understand factors that facilitate or hinder the adoption and scaling up of both modern and indigenous knowledge and adaptation strategies to enhance CC adaptation planning and implementation. The factors (many covered earlier) are complex, site and crop/system specific, and include socio-demographic, biophysical, economic, political, and institutional factors. At the household level, socio-economic factors include household income, material wealth, number of "hungry months," education, landholding size, land tenure security, and gender; institutional ones also include policies regarding access to rural institutions (Asfaw et al. 2014; Oxfam 2009; Ziervogel et al. 2008; Magombo et al. 2012; Gama et al. 2014). Thus, in their study, Asfaw et al. (2014), found wealthier and more educated households and those with more land were more likely to adopt both SLM and modern inputs than poor farmers with less land, while land owners with secure tenure were more likely to adopt SLM strategies (tree planting, legume intercropping, and soil and water conservation) than renters who tend to invest in short-term benefits of modern fertilizer and improved seed inputs. Male-headed households had a more pronounced yield dividend from the modern inputs than female-headed households, which had bigger gains from SLM strategies (Asfaw et al. 2014). This reflects other findings that women approach adaptation in a more holistic manner (ActionAid 2006; Oxfam 2009), and that gender-differentiated approaches are needed to understand CC impacts and identify adaptation interventions. Biophysical sensitivity of farm plots to disturbance favored the choice of tree planting and SWC, whereas social capital, rural institutions, and supply-side factors influenced all the SLM and modern strategies and enhanced system-level adaptive capacity (Asfaw et al. 2014). In

Chikhwawa district (Southern Malawi), access to extension services and higher food insecurity (number of months without sorghum or maize) were the most common factors that were positively associated with the likelihood of adopting indigenous adaptive/coping strategies (individually or in combination) to address climate variability and change generically, but they were particularly significant for crop diversification with or without irrigation and mixed crop/livestock practices (Magombo et al. 2012). Annual household income was negatively associated with adoption of any adaptive practice, but particularly so for crop diversification and organic manure use. Household size (labor) and age were positively associated with organic manure use with or without crop diversification. Such findings can be used to target particular groups of farmers with specific adaptation strategies or in retargeting extension efforts.

A study in the Southern Districts of Balaka and Mangochi shows that in addition to labor size, access to agricultural extension and farm size, access to rural credit, livestock wealth, and access to off-farm employment are also significantly associated with a higher likelihood of adopting improved maize varieties (Katengeza et al. 2012). However, adoption intensity was negatively associated with livestock wealth and fertilizer use, while household labor size, the age of the household head and the share of household members engaged in off-farm employment positively affected adoption intensity. While farmers who perceived drought risk or valued early maturity and drought tolerance traits are more likely to adopt and continue to use the improved maize varieties, poor yields and storability under drought conditions have turned some disappointed farmers away from using the varieties, highlighting the need for continued refinement of the varieties to address farmers' preferences for enhanced drought tolerance, early maturity, and storability (Fisher and Snapp 2014). For sweet potato varieties, early maturity, relay harvesting, and storability are also preferred traits under climate variability and change (Chipungu et al. 2012). As for policy, some negative impacts have been discussed earlier, including the promoting allocation of more land to maize and tobacco relative to other crops (groundnuts, soybeans, dry beans, etc.), thereby undermining crop diversification and CC adaptation (Chibwana, Fisher, and Shively 2012).

5.3. Weather-based Insurance and Adaptation to Climate Change and Variability in Malawi's Agricultural Sector

Studies also indicate the importance of diverse off-farm strategies mainly as short-term responses to climate variability and risk. They include paid piecework (*ganyu*), starting small-scale businesses (e.g., selling crop and livestock products, fritters, handcrafts, fish, charcoal and firewood), remittances and income transfers, and participating in food-for-work programs. Emigration is another strategy (Phiri and Saka 2008; Magombo et al. 2012). Desperation heightened by climate-related shocks and risk also forces some to extremes in order to survive, including vulnerable women selling their bodies for money and exposing themselves to exploitation and diseases (e.g., HIV/AIDS), or people turning to crime (ActionAid 2006; Wellard, Kambewa, and Snapp 2013; Kakota et al. 2011). Increased dependence on forest resources is another reactive adaptation/coping strategy among the rural poor, which leads to deforestation and associated environmental degradation including soil erosion (Fisher, Chaudhury, and McCusker 2010).[19]

[19] Farmers also use diverse short-term, crisis-coping strategies, including reducing the number of meals eaten per day, eating wild or less preferable foods, reducing expenditure on non-food items, begging, remittances or donations from friends, selling/exchanging household assets (livestock, household goods), borrowing money, participating in food-for-work programs, and emigrating (Magombo et al. 2012; Oyekale and Gedion 2012; Saka et al. 2013; Kakota et al. 2011).

Malawi is also well known as a positive example in Africa and among LDCs for experimenting with and later adopting index-based weather insurance (IBWI) in order to mitigate climate-related risk to the agriculture sector, particularly among smallholder farmers (Niang et al. 2014; Kapondamgaga and Fisher 2011). Starting in 2005 and with support from the World Bank, 892 smallholder farmers participated in an initial pilot index-based weather insurance scheme, expanding following year to 1,710 participating farmers and inclusion of maize (Hellmuth and Osgood 2009). The scheme involves insurance against weather-based (mostly drought or too much rainfall) crop failure bundled with loans provided by participating commercial banks, which are, in turn, backed by separate insurance, to support purchase of improved seed (initially groundnuts) and fertilizer. The scheme also seeks to reduce rates of loan default due to climate-based shocks (an incentive to commercial banks given the lack of or low collateral) and increase access to credit among smallholder farmers. Farmers are partially or fully forgiven the loans in the case of crop failure. The IBWI scheme was further expanded in 2007 to include tobacco farmers, who are relatively wealthy among smallholder farmers (Kapondamgaga and Fisher 2011). Although the pilot program has unlocked credit facilities for smallholder farmers, increased access to improved seed and fertilizers enabled participating farmers to mitigate drought risk, and generated interest among the banking sector, agribusiness, insurers, donors and the government, adoption remains low and limited to wealthier farmers for reasons including uncertain benefits, relatively high cost for poor farmers, lack of an "insurance culture" and low awareness of crop insurance and its benefits, poor weather data, and challenges related with production, marketing, and distribution (Giné and Yang 2009; Kapondamgaga and Fisher 2011).

Studies suggest that given the high poverty rates and other negative factors, the current form of IBWI is unlikely to catch on among most smallholder farmers in the near future, although better off and commercial farmers may be a more suitable target. A randomized field experiment of groundnut farmers investigating whether provision of insurance against a major production shock/risk causes farmers to take loans for adopting a new crop technology shows only a third of the 400 farmers offered credit for purchasing high-yielding maize and groundnut seeds in the 2006/07 season with a requirement for additional credit for purchasing crop insurance, 13% lower than uptake among the 400 farmers offered an uninsured seed-inputs loan (Giné and Yang 2009). Although the difference may be due in part to the farmers with uninsured loans having an implicit limited liability clause in the loan agreement (Giné and Yang 2009), a preliminary study in 2010 shows that burley tobacco production by smallholder farmers during a year with no rainfall shock is more profitable for farmers with an uninsured loan or no loan than for those with a weather-insured loan (essentially increasing the loan interest rate) although insured farmers would benefit and avoid loan default if a drought or too much rain occurred (Kapondamgaga and Fisher 2011). Long term, one study questions the financial viability of IBWI under projected future CC in Malawi, showing a reduction in financial robustness between 2008 and 2017, and steep declines by 2070-80 (Hochrainer et al. 2008). Kapondamgaga and Fisher (2011) recommend modification of the current IBWI to cover not only the loan, but also expected incomes for a tobacco farmer, and weather events other than drought and excessive rain to be added according to location. However, an insurance for work program in Ethiopia that allows the most resource-poor and marginalized farmers to afford insurance by working for the premiums in community-based risk reduction activities, such as SLM or improved irrigation (WFP 2011), can provide an outlet for Malawi's poor. Therefore, the future of CBWI for CC adaptation remains uncertain for Malawi.

5.4. Gender-differentiated Impacts of Climate Variability and Change, and Opportunities for Adaptation

Although there is growing recognition that women bear a disproportionate burden from adverse impacts of climate variability and change, such awareness has barely translated into gender-differentiated research, policies, and anticipatory adaptation interventions in Malawi (Oxfam 2009; Kakota et al. 2011). These gender disparities in vulnerability and impact occur because activities associated with their social roles as the main water and wood fuel collectors, farmers producing and ensuring daily access to food, and household caregivers are most adversely affected by climate variability and associated environmental degradation. For instance, women walk increasingly longer distances to collect water and fuelwood in Malawi (Oxfam 2009; Wellard, Kambewa, and Snapp 2012). Men's and women's perceptions of CC, exposure and sensitivity to climate risk, and responses thereto are filtered through their roles (Kakota et al. 2011). Additional stresses from women's poverty, limited access to credit, marginal role in decision making, other intra-household inequities, and the increasingly greater responsibilities that they assume in taking care of HIV/AIDs sufferers and orphans, all exacerbate women's vulnerability to adverse climate variability and change, and limit their ability to take advantage of climate-related opportunities compared to men.

The added vulnerabilities have forced some women to engage in transactional sex for money to buy food and other needs, thereby contracting and amplifying the spread of HIV/AIDS, which further undermines their adaptive capacity to CC (Oxfam 2009; Wellard, Kambewa, and Snapp 2012). A recent nationwide study showed empirically that gender affects choice and impacts of adaptive strategies (Asfaw et al. 2014). While male-headed households had a more pronounced maize-yield dividend from fertilizer and improved seed inputs than SLM strategies, this was not significant for female-headed households, which nevertheless had a higher yield increase from SLM strategies than from modern inputs (24% versus 16%). On the response side, women tend to approach adaptation in a more holistic way than men, including selecting SLM approaches which have the most potential for long-term agro-based adaptation, livelihood diversification, and improved services (e.g., HIV patient, orphan care), thereby freeing up their time and effort to engage in other productive activities, including accessing microcredit to start small businesses (Asfaw et al. 2014; Wellard, Kambewa, and Snapp 2012). Men tend to focus on cash-crop based strategies.

Adaptation strategies can have indirect impacts on women and gender relations. For instance, farming system diversification, including integration of small livestock, increased maize-legume intercropping, fruit trees, and fodder crops not only enhance farming systems resilience, but also can reduce widespread under-five child under-nutrition, improve nutrition of HIV/AIDS patients, and enhance food security under adverse climate conditions (Bie, Mkwambisi, and Gomani 2008; see also Kerr et al. 2007). Avoiding overburdening of women with labor-intensive adaptation strategies (Asfaw et al. 2014) will free their time and energy for other productive and climate-smart interventions. Remittances can also help enhance women's, adaptive capacity and agricultural system resilience (Bie, Mkwambisi, and Gomani 2008), particularly in female-headed households. However, more research is needed to study gender-differentiated impacts and vulnerability to CC and adaptation responses. Women bring specialized knowledge, skills, creativity, and social capital for collective action that can enhance adaptation effectiveness if recognized, tapped, and carefully cultivated to complement men's (Wellard, Kambewa, and Snapp 2012).

6. Research Gaps and Capacity Challenges

Climate change research in Malawi operates under poor resources, data, infrastructure and human and institutional capacity, which undermine the contribution of research to CC generally and adaptation in particular. Research gaps are many. The main ones include improving climate change modeling and projections to finer actionable spatial scales and with lower uncertainty, especially for precipitation; assessing future CC impacts on major crops though crop modeling (Asfaw et al. 2014; Gama et al. 2014); and vulnerability/risk assessment of farmers that includes a robust understanding and separation of diverse contextual factors from CC effects (Ziervogel et al. 2008; Saka et al. 2013; Gama et al. 2014). Building on analysis of the impacts of past climate variability (e.g., Nicholson, Klotter, and Chavula 2014), analysis of future CC impacts can include field-based social analysis of levels of vulnerability of smallholder farmers and identify innovative and scalable adaptation practices for particular cropping systems in the context of broader livelihood-based coping and adaptation mechanisms (e.g., resource allocation, cropping decisions, energy expenditure, water use and allocation) and during scenarios of severe drought and flooding relative to a "normal" baseline.

In particular, very few studies have used crop models such as DSSAT to predict impacts of future CC on particular crops in particular agro-ecological zones and settings, which is a useful tool to screen the suitability and effectiveness of alternative adaptation strategies (e.g., Asfaw et al. 2014; Ngwira, Aune, and Thierfelder 2014). For instance, only one published study (as of January 2015) has modeled CC impacts on rain-fed or irrigated rice (Daccache, Sataya, and Knox 2014). This is a significant research gap considering that many rice irrigation schemes already face water shortages and operate well below capacity during the dry/irrigation season. Further research is needed to enhance the robustness of drought-resistant and early maturing varieties of maize and other key crops while also incorporating local indigenous knowledge and trait preferences, such as productivity, storability, diseases resistance and others (Fisher and Snapp 2014). Integrating indigenous and scientific knowledge and strategies to enhance use of climate/CC information, adoption of adaptation strategies, and effectiveness of adaptation remains an understudied area with significant potential research and practical dividends (e.g., Garrity et al. 2010; Kalanda-Joshua et al. 2011; Chipungu et al. 2012; Magombo et al. 2012).

Additional on-farm participatory research with farmers is needed to improve screening of promising climate-smart adaptation technologies co-selected with farmers for relative effectiveness on various criteria (e.g., GoM 2011b; GoM 2012). More causal analysis of adoption behavior and search for effective education and extension methods for scaling selected strategies up to more smallholder farmers is now needed, including within FISP (IFAD 2011; Asfaw et al. 2014). This need includes examining the role of social learning in facilitating or hindering adoption of adaptation strategies, including the use of participatory modeling of decision-making processes. Since the mother-baby trial approach and farmer field schools already show some promise for Malawi (Snapp 1999, 2002; Kerr et al. 2007; Bezner Kerr, Berti, and Shumba 2011; Snapp et al. 2013), new research can build on these efforts, especially on mixed maize/legume systems. There is also a lack of research on community-based adaptation in agricultural responses to CC, to examine what and how community-level factors including social capital and learning, and collective action can facilitate or hinder effective adaptation.

As for enhancing crop diversification to enhance CC resilience, more research is needed on non-major crops including cereals (rice, wheat, millet), legumes and oilseeds, root tubers, horticultural crops, cotton and others. Mixed maize systems that integrate multi-purpose annual and semi-perennial legumes such as pigeon peas through intercropping and/or rotation show significant early promise for long-term adaptation while also enhancing soil fertility, yields, incomes, nutrition, fodder, and wood products (e.g., Kerr et al. 2007; Bezner Kerr, Berti, and Shumba 2011; Mhango, Snapp, and Kanyama-Phiri 2013; Snapp et al. 2013; Ollenburger and Snapp 2014), but more work is needed to demonstrate "proofs of concept" as a basis for wider adoption (Asfaw et al. 2014). Lack of research on the role of livestock or integrated crop/livestock systems in CC adaptation beyond the role of a short-term safety net particularly stands out as a research gap (Oyekale 2012).

More research is also needed to examine gender-differentiated vulnerability to and impacts of CC, and utilize the unique knowledge, skills, and other resources that women bring into adaptation practice in synergy with men's contributions (Asfaw et al. 2014; Kakota et al. 2011). Ultimately, because adaptation is a social learning process that takes time, there is need for patience and for longer-term and flexible funding that accommodates integration of research, policy, and implementation, allowing intentional co-learning and network building among diverse stakeholders, including farmers, extension agents, NGOs, the private sector, researchers, and even donors, rather than just funding researcher-driven or intervention *projects* (Ziervogel et al. 2008).

Finally, recent CC training and institutional capacity needs assessments generically (GoM 2011c, 2011e) or for research in particular (e.g., Lotz-Sisitka and Urquhart 2014), identify many needs on adaptation, mitigation, and crosscutting issues. For adaptation, gaps included climate change modeling/projections; crop modeling under CC scenarios; geographic information system (GIS) including hazard mapping; land cover and land use analysis, environmental impact assessment; integrated soil and water management; CC links to food safety, disease control and management, and urbanization; flood forecasting and early warning systems; and adaptation costing. Relevant gaps related to mitigation include policy analysis and development, climate mainstreaming, CC risk assessment, hydrometeorological statistical modeling, and mathematical modeling.

7. Conclusions

This technical report summarizes existing knowledge, research, and gaps on impacts of and responses to climate change for the agriculture and farming communities in Malawi primarily from a review of both published peer-reviewed literature and gray literature. It also briefly covers research and adaptation capacity needs. Malawi is among the dozen most vulnerable countries globally in terms of adverse effects of CC, especially drought, but also floods/heavy rains. Heavy dependence on rain-fed agriculture of both the national and local economies, and for the livelihoods of the majority (85%) rural population makes Malawi particularly vulnerable. Factors including high population density and poverty, small landholding sizes, and the low-input low-output farming systems exacerbate farmers' vulnerability and reduce the resilience of agricultural systems and adaptive capacity of farming communities to effectively respond to adverse CC impacts or take advantage of emerging opportunities. Understanding the status and shortfalls in knowledge on CC in agriculture provides a baseline for diverse stakeholders to use in enhancing medium- to long-term CC adaptation policies, and planning and implementation of sustainable and climate-proofed (maize-based) food-system innovations that enhance yields, food security and incomes for smallholder farmers while also positioning agriculture to contribute to CC mitigation.

Farmer and scientific perceptions of recent climate variability/change generally agree on temperature but diverge on rainfall. Both show increasing trends in temperatures (0.9°C observed 1960-2006), dry days, hotter summers, drought and flood frequency, and inter-annual variability in rainfall. Contrary to common farmer perceptions of declining total annual rainfall and their delayed start and earlier cessation, no study showed evidence of significant long-term shifts in total rainfall and timing. However, discovery of a significant geographic (north versus south) and temporal (before and after a detected dry spell in mid-February) bifurcation in Malawi's rainfall and circulation regime can help to improve in future CC projections. The discrepancies in farmer/scientific perceptions of CC reflect miscommunication that can lead to mistargeted, suboptimal, or locally inappropriate strategies; promote short-lived coping or reactive strategies over long-term, anticipatory, or proactive strategies; undermine farmer confidence in formal weather forecasting or CC information and its use along with the associated agricultural extension advice; and ultimately undermine CC adaptation or lead to maladaptive strategies. Because perception is reality, successful adaptation will require reconciling the divergent perceptions and integrating compatible indigenous and scientific knowledge to ensure that famers, extension agents, managers, policy makers and scientists understand what is changing with weather/climate, how, where, and what they can do about it.

Projections show mean annual temperature increases of 1-3°C by 2050, with more variability in total annual rainfall from no change or modest declines to increases of over 45-400 mm. Predicted CC impacts vary similarly and by crop. For the staple food crop, maize, predicted yield changes (2010-2050) range from -25% to +25%. Cotton, cassava, and other tubers show the highest potential gains in productivity and exports, under CC. However, high levels of uncertainty remain across CC projection models (GCMs or their scaled-down regional versions), and in associated CC impact assessments. Further, diverse socio-demographic, economic, ecological, and geographic factors influence CC impacts, making for spatial variability, both economic gains and losses, and winners and losers. CC adaptation should also prepare farmers to capitalize on emerging opportunities under future CC.

While acknowledging significant progress in policy and institutional responses to CC nationally, analysis shows that the responses are still inadequate and more supply-driven either in response to Malawi's planning and reporting obligations to the UNFCCC (e.g., the NAPA or national communications) or external donor influences than being proactive in response to local demand. Gains in elevating CC issues among Malawi's nine national development priorities (MGDS II for 2011-16) and providing a foundation for mainstreaming CC in sector development policies, and in establishing institutional structures and instruments for national and cross-sector coordination among key government, academic, NGO, private sector, and donor agencies and communities on CC issues, and efforts to create a more conducive policy environment and tools, are yet to translate into harmonization of sector policies, adequate anticipatory adaptation interventions, and cross-project coordination to enhance farming systems resilience and farmers' adaptive capacities. ASWAp improves on the NAPA as the two main policy instruments outlining key CC adaptation strategies in agriculture (an advanced draft National Climate Change Policy will broaden the scope), and the number of adaptation interventions is increasing. However, there is still a need to integrate CC considerations explicitly into current and future major agricultural program, including FISP, and increase resources for meaningful adaptation among smallholder farmers.

Studies document diverse, locally specific, indigenous, and modern strategies that farmers have adopted in response to perceived climate variability and change (mainly droughts, dry spells, and rainfall pattern changes/variability), but these are mainly autonomous, short-term/coping or reactive strategies rather than planned, anticipatory or long-term ones. Strategies include climate-smart inputs such as drought-tolerant seed varieties, practices including crop diversification and irrigation, and agro-ecological systems such as intercropping and conservation agriculture, sustainable land management systems, integrated crop/livestock systems, and agroforestry. Studies also identify many diverse, complex, and site-, crop- and intervention-specific socio-demographic (including gender), economic/market, institutional, and biophysical factors that influence adoption of particular strategies. Access to extension services, food insecurity, socio-economic status, and perception of drought risk or biophysical sensitivity were particularly important. This information can be used for differentiated policy strategies and targeting of strategies to particular demographic groups and agro-ecological zones, and as a basis for anticipatory adaptation projected future CC.

Many research gaps and resource constraints remain. These include improved future CC projections scaled down to a level appropriate for decision making, predictions of impacts of future CC on agriculture and particular key crops empirically isolated from contextual factors, development and/or screening of (best bet) adaptation strategies that demonstrate proof of concept to enhance adoption and scaling up, and more robust analysis of factors that facilitate or hinder current and future adoption of climate-smart strategies to enhance extension targeting and strategy uptake. Assessing optimum ways to integrate indigenous and scientific knowledge, including weather forecasting and CC perceptions, CC strategies, and incorporating traits that farmers prefer into more robust drought-resistance crop varieties would enhance policies and adoption of CC adaptations, but is understudied. More robust research is needed on CC policy and impact analysis, farmer social learning or adoption behavior and effective extension and public education methods. Production of usable climate information and integrating science into climate-related decision making by policy makers and farmers is needed. Participatory research and other methods (e.g., mother-baby trials and farmer field schools) to co-develop and promote adoption of appropriate climate-smart strategies shows promise and needs more focus. Also relatively neglected is research on gender dimensions of CC vulnerability, impacts, and adaptation strategies; livestock and livestock/crop systems, pests and diseases in relation to CC and adaptation; and community-based adaptation.

Finally, major capacity gaps undermine research, policy, and implementation of CC adaptation. They include data availability/quality, human analytical capacity, financial resources and research infrastructure, and institutional support. Human capacity needs for research include modeling (CC projections, crop modeling, mathematical and dynamic modeling, and participatory modeling decision making), geospatial analysis, integrated/interdisciplinary analysis, and core disciplinary training (climate change science, meteorology, and climate change adaptation, social policy analysis and impact evaluation).

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