A systems evaluation of smallholder adoption of climate information services for resilience in Uganda:
Socio-economic incentives, limitations, and implications.

By

Simon Peter Muwafu

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Supervisor: Prof. Kopainsky Birgit (Ph.D.)

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To God be the Glory.

Abstract

Understanding the level and drivers of adoption of Climate Information Services (CIS) among smallholder farmers in Uganda is needed to stimulate large-scale uptake of climate information services. Although climate information services are expected to improve the capacity of Uganda's agricultural sector to manage the risks of climate variability and change, a lack of evidence regarding the adoption and diffusion of these services in Uganda presents a realistic analysis of whether these services are delivering on their potential.

The adoption and diffusion of agricultural technologies such as climate information services is a gradual process; it takes time for information and knowledge about these practices to be widespread within the smallholder farming community. This study seeks to identify the best combinations of interventions that can increase the adoption and diffusion of climate information services among smallholder farmers in Uganda.

A System Dynamics model simulates the current dynamics in Uganda's climate information services sector based on data gathered from both government and development organization initiatives. An analysis of the behaviour patterns that are generated by the model structure can enable to identify a combination of intervention in the different parts of the adoption process that can support the adoption and diffusion of climate information services among smallholder farmers in Uganda.

Contents

Chapter: Introduction

Background

Variations in weather conditions and climate patterns have increased in Uganda over the last couple of decades, triggering declines in agricultural yields and escalating smallholder farmer vulnerability (Mubiru, et al., 2012). Coupled with high deforestation rates and a rapid annual population growth rate of 3.03 per cent, climate-related incidents like droughts, floods and extreme temperatures negatively impact Uganda's food security and economic welfare (UNECA, 2016; Parry, et al., 2007).

Recent studies on climate and meteorology, project a significant increase in climate variability and extreme events in Uganda (Niang, et al., 2014; IPCC, 2014). Increased variability of weather patterns affects rainfall patterns mostly when rains are delayed or come earlier than usual. Such variation places a considerable constraint on farmer's ability to make strategic agricultural farm decisions.

It also disrupts the lives of over 72 percent of Uganda's population who live in rural areas and depend on rain-fed smallholder agriculture for their livelihood (UBOS, 2017). Many farmers in Uganda express frustrations about the inconsistency in weather and the inability to rely on their traditional ecological knowledge (TEK) to cope (Kaweesa, 2020).

In Uganda, the government has undertaken extensive economic recovery reforms to stimulate financial progress and decrease poverty levels among smallholder farmers in rural areas with low productivity (Ministry of Finance Planning and Economic Development, 2002).

These efforts include various methods of financing and delivering demand-driven extension services to rural smallholder farmers, such as working with the relevant government institutions like the Uganda National Meteorological Authority (UNMA) and the Ministry of Agriculture to beef up efforts of bringing decision-making closer to the farmers.

Uganda National Farmers' Association (UNFA) operates through a regionalized structure in several districts, UNFA district organizations work independently with some degree of support from the centre. Through donors' support, UNFA has conducted capacity building and development activities, including training, information services, institution-building activities, credit provision, advisory services education programs. (Ministry of Finance Planning and Economic Development, 2002).

The Agrometeorology Division of The Uganda National Meteorological Authority generates weather forecasts and climate advisories, to distribute to the farmers. Under several partnerships, the Authority collaborates with other government and non-government institutions to disseminate climate information services to farmers to enable them plan agriculture operations in a way that minimizes the damage of crops under adverse weather conditions (UNMA, 2017).

Climate information services reportedly reach more than 80 per cent of Ugandan farmers; however, only a handful of Ugandan smallholder farmers adopt the weather information services into their farm decision making (Vaughan, et al., 2017). Studies still show that there are constraints to adoption of these services related to issues such as affordability of access, understanding, and capacity to respond to such information.

Analysis of literature on the subscription of climate information services in Uganda shows that users typically include farmers who generally are better educated and use newer farming and technological practices relative to most (Freeman & Qin, 2020). Although these farmers may share climate information and advice on farming practices with other farmers, the use and awareness among marginal smallholder farmers, is still low (Bamutaze, et al., 2019).

Problem Formulation

The UNMA informed in an interview that farmers who subscribe to climate information services receive weather forecasts, seasonal forecasts, and various agriculture advice. Newspapers and televisions are the primary sources of such climate information and seasonal information (UNMA, 2017).

Whereas many farmers know about climate information services, the adoption rate of climate information services by smallholder farmers in Uganda highlights an inconsistency in the levels of access and actual adoption of the services. Most farmers continue to rely on TEK as an indigenous way of forecasting.

It, therefore, places a high demand on the capacity of climate service providers to present and communicate weather forecast and climate advice in a way which facilitates access and adoption (Tall, et al., 2014). The complexity of the different decision-making factors and mechanisms during the adoption process complicates the task of correct interpretation of farmer adoption of climate information services.

Data about the adoption of climate information services in Uganda is scarce. Available literature and data highlights that the adoption rates of climate information services as an agricultural innovation are low. Only about 10 to 18 percent of smallholder farmers in Uganda, adopt climate information services into their farming planning processes (Vaughan, et al., 2017).

This study develops a system dynamics simulation model that captures the basic processes influencing farmer decision making when adopting climate information services as an agricultural innovation for climate adaptation. The simulation model structure builds on an extensive review of the literature on the adoption and diffusion of agriculture innovations.

Although much literature is available, most of it tends to focus more on the technical aspects and less on the feedback processes that correlate the benefits that farmers gain from investing in accessing these innovations, with the decisions to adopt these innovations.

The developed system dynamics model integrates the different adoption elements and their interactions as found in the literature, to represent the feedback process of climate information adoption. The model analyses the behaviour patterns generated by the structure and identifies parameter patterns that cause observed behaviour patterns in the adoption process of climate information services in Uganda.

Conclusions derived from the model enable the construction of effective strategies for improving the adoption and diffusion of climate information services in Uganda.

Research Objective

The research objective is to gain insights into the low levels of smallholder farmer adoption of climate information services as an innovative adaptation strategy to climate change in Uganda.

The study intends to identify the underlying causal relationships linking the different factors within the adoption process of climate information services and to understand the behaviour that these mechanisms give rise.

The defined dynamic causal relationships enable the construction of a dynamic system model, which can enable the identification of effective strategies for advancing the adoption and dissemination of climate information services in Uganda.

Hypotheses

The following hypotheses guided the scope of the research study:

1. Limited trust in distributed climate information services hinders their adoption.

Although climate information services can help smallholder farmers in Uganda to manage climate-related risks and adapt to the changing climate, significant gaps exist in the level of trust that farmer communities have in absorbing climate information, as this means shifting their decision-making trends and costly investments.

Moreover, this trust gap is compounded by the constrained provision of precise weather information in Uganda consequently making smallholder farming in Uganda a risky business (Anderson & Robinson, 2009; Mubiru, et al., 2012).

In Hoima Uganda, findings showed that most farmers rely on TEK and weather information from elders. Most households trust this indigenous knowledge from elders, based on experience; besides, the respect for elders ensures natural adoption (Radeny, et al., 2019).

2. Limited knowledge and understanding of the distributed climate information services impede adoption.

Language barrier, content and weather information formats are some of the communication factors that further compound the adoption of weather services in Uganda. In Sub Saharan Africa, very few National Meteorological and Hydrological Services translate their forecasts beyond English, potentially excluding the most vulnerable yet essential sectors of the target population (e.g. smallholder farmers, pastoralists, fishers) from receiving and using the forecasts (Tall, et al., 2014). There is inadequate consideration of the weather information comprehension by smallholder farmers at the community level. Additionally, the probabilistic nature of weather and climate information is at times misinterpreted and leads to confusion if translations of information get manipulated.

3. Farmers' limited capacity to afford access to climate information services constrains adoption.

In most Ugandan farmer communities, accessing climate information services usually competes with other livelihood demands that can provide compelling reasons for farmers not to heed to an equally crucial climate-related reason. (Vaughan, et al., 2017). These demands and reasons are mostly in the form of inadequate resources to afford climate information services, farmer climate risk perception, as well as the range of non-climate related factors that the farmers must take into consideration.

4. The shortage of government and development outreach to smallholder farmers at the community level constrains farmer adoption of climate information services.

The current processing and delivery design of climate information fail to reach farmers who dwell in remote geographic areas in Uganda. There is a lack of operational community-level transmission of climate information. Media outlets, as well as other information-sharing systems which aim to ensure that climate information trickles down to the farmers that need it, at times, complicate the situation even further (Tall, et al., 2014).

Research Questions

This research study adopts the following research questions:

1. What factors influence smallholder farmer adoption of climate information services in Uganda?
2. What are the causal feedback mechanisms within the factors influencing smallholder farmer adoption of climate information services in Uganda?
3. What effective policies can improve the adoption of climate information services in Uganda?

Thesis Scope

The study will examine the adoption of climate information services among smallholder farmers in Uganda over twenty years from the year 2001 to 2020. Emphasis is on the feedback processes that correlate the benefits that farmers receive from investing in accessing climate information services with the decisions to adopt these services as an agricultural innovation.

The study will approach the hypotheses in the following manner: The farmer trust hypothesis examines the role that trust plays in the adoption of climate information services as an agriculture innovation.

The knowledge and understanding hypothesis assess how the level of farmer expertise and grasp influences the adoption of climate information services. Knowledge and understanding assume the ability to interpret and translate climate information into workable actions suited to the local context. Based on farmer perspectives, climate information usefulness, however, depends on the credibility of the information (Venkatasubramanian, et al., 2014; Stigter, 2010).

The affordability hypothesis explores the effect of household incomes on the affordability of adopting climate information services among smallholder farmers in Uganda. Television sets and mobile phones are the primary channels for distributing climate information to farmers; however, usage in rural Uganda is still incredibly low, and teledensity varies. The economic situation among farmers determines the affordability of access to climate information services.

The outreach hypothesis analyses how stakeholder contact rates at community level affect the adoption of climate information services as an agriculture innovation. Social learning through collective engagement and dialogue with others is an approach which is essential to explore.

Adoption of climate information services implies when a smallholder farmer considers climate information, meaning either weather forecast, seasonal forecasts during agricultural decision-making circumstances.

Thesis Outline

This study comprises six chapters. The first chapter comprises a brief background of the study, its problem statement, research objectives and questions, a brief on information collection and validation techniques.

The second chapter covers the theoretical background upon which the study builds. It comprises of insights from the literature on climate change and risks in Uganda, agriculture production, household incomes, and climate information services among smallholder farmers in Uganda.

Chapter three describes and documents the model of the designed system. The next two chapters discuss the model validity, behaviour analysis and developed policy insights, respectively. The last chapter, six, discusses the different conclusions and recommendations identified in the study.

Chapter: Theoretical Background

This chapter analyses relevant literature used to classify the boundaries of the study and determine the underlying assumptions of the developed model. A literature review on smallholder agriculture and the adoption of climate services intends to evaluate their relevance amidst changing climatic conditions and the characteristics of farmer decision making during adoption. The chapter features different aspects of smallholder productions, threats and coping mechanisms to climate risk, climate information services as a coping mechanism for smallholder farmer livelihood in the face of climate change and the adoption of climate information services as an agriculture innovation.

Smallholder Agriculture Production in Uganda

Uganda presents an admirable example of a highly dynamic and productive agricultural sector mainly due to its favourable agro-climatic conditions that allow farmers to enjoy two seasons of crop per year (Leliveld, et al., 2013). The Ugandan agricultural sector is characterized by smallholder farmers, mainly relying on low-cost inputs and labour-intensive farming (Anderson, et al., 2016). These farmer households are throughout Uganda, with the largest concentration in the Eastern and Western parts of the country.

The Northern part of the country makes up about 23 per cent of smallholder farm households and has the highest poverty levels in the country, while the Central region comprises the smallest percentage(16) of smallholder farm households (Anderson & Robinson, 2009). Whereas smallholder households in Uganda are male-dominated, women play an essential decision-making role during agricultural activities of the household. (Sebatta, et al., 2014).

The role of smallholder agriculture towards sustainable food production, though usually not measurable, is irrefutable for the reason that smallholder farms make up a majority of the agricultural sector in Uganda (Leliveld, et al., 2013). Land and labour constitute the primary means of production for smallholder farmers to derive a livelihood. For these farmers, agriculture provides the main income stream into the household and supports all the household activities. Typically, Ugandan smallholder farmers cultivate between 0-2 acres of land which many own through a lease or certificate, or under customary law (Pouw, 2008). Most farms fall under customary law which means there is usually no official documentation of ownership.

Household composition and size play an essential role in farm labour. Though these vary across the country, the average smallholder farmer household size is eight people (Anderson, et al., 2016). The presence of smallholder households with bigger sizes than average may point to the overall flexibility of household circumstances. Age distribution within smallholder farmer households is even. (Anderson, et al., 2016).

Smallholders in Uganda grow staple and cash crops. The most common are maize and beans, followed by cassava, sweet potatoes, and groundnuts. Production is for home consumption, and any excess gets sold off to earn an income. Only a small percentage grow cash crops, which tend to be coffee and sugar cane (Anderson, et al., 2016). The productivity of smallholder farms is often constrained by a lack of appropriate technology, input services and credit and farmers inability to bear the risk (Ambayeba, 2018). Smallholder farmers often sell their excess produce right after harvesting when the supply is much higher than the demand. As a result, the prices are typically low and unreasonable. (Mubiru, et al., 2009).

Farmers are often at the mercy of nature when it comes to production. Inadequacies in institutional structure may limit farmers' access to innovative approaches to help improve their production in the face of climate risks. Smallholder households still often fall short of their monthly needs and end up mostly living at the poverty line or in extreme poverty (Pouw, 2008).

Climate Trends, Threats, And Coping Approaches of Smallholder Farm Households

Smallholder farmers in Uganda increasingly face a wide range of agricultural production risks, including climate-related risks. Climate disparities complicate farmers' plans for critical activities like timely planting of crops, and negatively impact soil moisture content, leading to either reduced yields or total crop failure (Mubiru, et al., 2009; Mubiru, et al., 2012).

Previous studies have established that farmers understand that the climate has changed in the last two decades (Mubiru, et al., 2009; Osbahr, et al., 2011). In response, farmers in Uganda form local coping approaches through local knowledge to increase their resilience and adaptive capacity. Such local coping methods are often not documented but rather handed down through oral history and local expertise (Majaliwa, et al., 2009). However, the capacity of indigenous knowledge and traditional coping practices in adapting to climate change and variability is likely to be surpassed by the magnitude of changes expected from increased risk exposure.

Local coping strategies differ among households and communities depending on the farming system, resources available and social capacity. For smallholder farmers, these coping strategies can only help in the short-term (Boko, et al., 2007; Orindi & Murray, 2005). In order to build effective strategies for managing and coping with extreme weather and climate variability, farmer communities and households need to learn how to differentiate and adjust to climate-related risks continuously.

A better understanding of climate-related risks among farmers, and their impacts on crop production, form the basis for constant learning and selection of farmer innovations that are likely to enhance adaptive capacity**.**

The Government of Uganda identified the improvement and sustenance of agricultural advisory services that include climate information services for agriculture as part of its strategic priorities for agriculture development (GOU, 2015). Climate information services which involve the production, translation, transfer, and use of scientific information for decision-making, are receiving increasing attention globally as an essential component of the agenda on climate adaptation (Hansen, et al., 2014; Zillman, 2009).

Climate Information Services as An Innovative Coping Strategy to Climate Variability

The production and delivery of climate information services as an agriculture innovation is part of a complex multiple-layer agriculture value-chain development system. It involves the assembly, translation, transfer, and use of scientific climate information (Vaughan, 2017) for farm decision-making, with a purpose of facilitating smallholder participation in higher-value markets for their agricultural products (Orr & Donovan, 2018).

These products and services are innovative approaches that can increase the preparedness of the farmers, well in advance, to cope with uncertainties (Tall, et al., 2012). Mounting evidence on the value of climate services for improved decision-making in agriculture, disaster management, and water management has played a vital role in making a case for climate information services (Hansen, et al., 2011; Hellmuth, et al., 2007).

In Uganda, the government and several agriculture institutions have been developing skills in predicting weather patterns, creating forecasts, and combining them with improved communication channels to enable distribution of climate information for farmers in rural areas. The UNMA generates weather forecasts and climate advisories to distribute to the farmers (UNMA, 2017).

Under several partnerships, UNMA collaborates with other government and non-government institutions to disseminate agricultural climate information to farmers to enable them to plan farming operations and minimize crop damage under adverse weather conditions. UNMA also monitors and collects agriculture data from the National Agricultural Research Organisation centres. Based on the data gathered, UNMA quantifies the impact of climate information services on agriculture and collaborates with the Food Security Department to advise the government on the food security situation (UNMA, 2017).

Despite evidence regarding the effectiveness of climate information services in agriculture, Uganda still grapples with the complexities of producing, communicating and evaluating climate information services that address smallholder farmer decision-making needs under a changing climate (Mubiru, et al., 2012).

Evaluating the usage of climate information services in agriculture is primarily concerned with:

(1) Verifying the extent to which potential users can access and use services (Adoption)

(2) Assessing the actual or potential impact and value of services (Impact)

(3) Identifying the elements of design and implementation that lead to better outcomes concerning access and impact (Design)

(Vaughan, 2017).

Recognizing the level of adoption of climate information services is a fundamental step in evaluating the impact of the services. However, different characteristics of climate information services impose challenges to evaluation (Tall, et al., 2018). The non-exclusionary nature of climate information services implies that information can quickly pass along social and family networks. However, the information transferred via informal networks may be incomplete or altered hence making it difficult to differentiate between those who receive the service and those who do not.

Secondly, because of the technical nature of climate information services, the use, impact, and even the mechanism of distribution can vary per year. The required number of years to sample the range of variability, and hence provide reliable estimates of use and impact, can exceed typical evaluation cycles. Furthermore, climate conditions during evaluation cycles may confound cumulative indicators of impact, making it difficult to distinguish between the benefits of the service. (Vaughan, et al., 2017).

Thirdly, the impact of climate information is a result of changes in management decisions, which are not only influenced by agricultural development interventions, but also farmers' different goals, skills, and constraints.

The fact that climate information is one of many interacting elements that influence decision making and determines livelihood impacts makes it complicated to isolate the relative contribution of the services. This difficulty implies that causal pathways between access to climate information and adoption can vary among farmers. (Vaughan, et al., 2017). Studies on the determinants of adoption of innovation technology mostly categorize these determinants in ways that best fit the context of any study.

Adoption and Diffusion of Agriculture Technology

Adoption and diffusion are the processes that regulate the utilization of innovation. Although many authors differently define adoption, a common theme among all these studies is the analysis of factors that affect a farmer's decision to attempt using innovation and continue using it over a while. It is a mental process that a farmer goes through from knowing about innovation to finally use it (Kirinya, et al., 2013).

The relative rate at which farmers utilize an innovation defined as the adoption rate, includes the aspect of time, the degree of use, as well as the intensity of use of that innovation within a given period (Mwangi & Kariuki, 2015). Implementing the adoption decision is as a result of a series of individual decisions, and these decisions are usually the result of making a comparison between the likely benefits of the new technology and the indefinite costs to be incurred (Hall & Khan, 2003).

Conventionally, the cost and benefit analysis, rationalize the adoption dynamics relative to individual characteristics, resources, the information quality that an individual obtains, risk and uncertainty levels, institutional constraints, infrastructure, and availability of the innovation. However, new literature on adoption highlights the impact of social networks and learning on the level of technology adoption. In this case, determinants of agriculture technology adoption include the economic, social, and institutional factors (McNamara, et al., 1991).

Relevant to this study, farmers' decision to adopt innovative agriculture technology depends on the dynamic interaction between the characteristics of the technology itself and their conditions and circumstances (De Janvry, et al., 2017). Studies on diffusion, on the other hand, define it as an aggregated form of adoption, and its analysis bases on how an innovation penetrated the potential market. The potential market suggests the share of farmers who use the technology or the portion of total agricultural land on which the technology is under use (McNamara, et al., 1991).

Socio-Economic Factors Affecting Adoption of Agriculture Technologies in Uganda

Household size negatively influences adoption. The probability of adoption decreases for every increase in family size by one member (Nnadi & Nnadi, 2009).

Household income can significantly and positively increase the probability of adopting technologies (Bonabana-Wabbi & Taylor, 2012). Due to problems of inadequate finance for the agricultural sector, income sources solve liquidity restrictions in production which boosts the adoption of technologies (Nkonya, et al., 2002).

Education has got both a positive and significant influence on the probability of adoption of technologies (Moyo et al., 2007; Mugisha et al., 2004) This adoption is because education reduces the amount of apparent complexity about a technology thus boosting a technology's adoption. Additionally, as farmers get more educated, they search for and process information as well as understand the technical aspects of technology and are likely to adopt technologies compared to the less educated farmers. The latter would not want to risk with new technologies until they have confirmed the benefits (Mugisha, et al., 2012).

Age of the household head has can negatively influence the adoption of improved technologies (Moyo, et al., 2007). An increase in the age of the household results in a decline in the probability of adoption (Baidu-Forson, 1999).

Technology Related Attributes and Perceptions Affecting Technology Adoption

Farmers' perceptions regarding the technologies significantly influence both probabilities of adoption of technologies and lead to mixed results on adoption decisions. For example: while perceived yield gains due to technology adoption in the previous season positively influence the adoption of the technology in production in the subsequent season, farmers' perceptions of a yield loss in the last season negatively influenced the adoption of a technology (Bonabana-Wabbi & Taylor, 2012).

Institutional Factors Influencing the Adoption of Technologies in Uganda

Access to credit is positively related to the adoption of technologies. Access to credit in production enhances adoption intensity because credit eases the liquidity constraints needed to invest in affording technologies to conduct production.

Membership to a farmers' organization positively influences the adoption of agricultural technologies because group membership enhances learning, information sharing and fosters technology uptake. Receipt of extension training and knowledge about improved production technologies significantly influences adoption because extension training enhances farmers' knowledge on production and equips the farmer with new techniques for managing agricultural production.

Extension visits facilitate the farmer to get information about new or improved technologies, and the extension workers encourage them to adopt. Established relationships between agents and farmers allow them to participate in training and demonstrations (Bisanda, et al., 1998).

However, information from extension agents can have a negative impact because of limited knowledge on the side of the extension agent to advise the farmer fully. Conflicting messages between the researchers and extension agents disrupt the farmers' decision-making process on whether to adopt technologies or not.

Land tenure security can positively influence the adoption of technologies. Having a freehold tenure status positively influences the adoption of new technologies because a farmer is stable enough to conduct production unrestricted. Besides, with freehold tenure, farmers can access financial resources which can help them obtain improved agriculture technologies. It is easier for micro-finance institutions to lend to a farmer who has a stable land tenure-ship and collateral than one without.

For this study, the determinants of adoption and diffusion of climate information services as an innovative agriculture technology are motivated by classification into varietal characteristics, farm-level characteristics, farmer characteristics and institutional characteristics. (Kopainsky & Derwisch, 2009). The developed system dynamics model considers the endogenous interactions between farmer characteristics determinants such as farmer knowledge and expertise about climate information services, farmer income which is a significant determinant of farmers ability to afford access of climate information services and the institutional determinants such as government and development organizations outreach.

Chapter: Model Description

Recognizing the relationship between interventions and results in a multi-layered system necessitates knowledge about the structure and dynamic aspects of the system. System dynamics models replicate a system based on assumptions about the structure and strength of interactions within this structure, but it is crucial to comprehend those interactions accurately enough to model them.

This chapter presents a comprehensive explanation of the model structure developed to investigate the research questions of this study. It accounts for the assumptions made during an iterative learning and model development process that aimed to analyses and synthesize adoption determinants and their relationships as found in the literature. The chapter also provides a critical assessment and a discussion that describes how the interconnections within the structure, result in the adoption of climate information services to improve farmers' resilience.

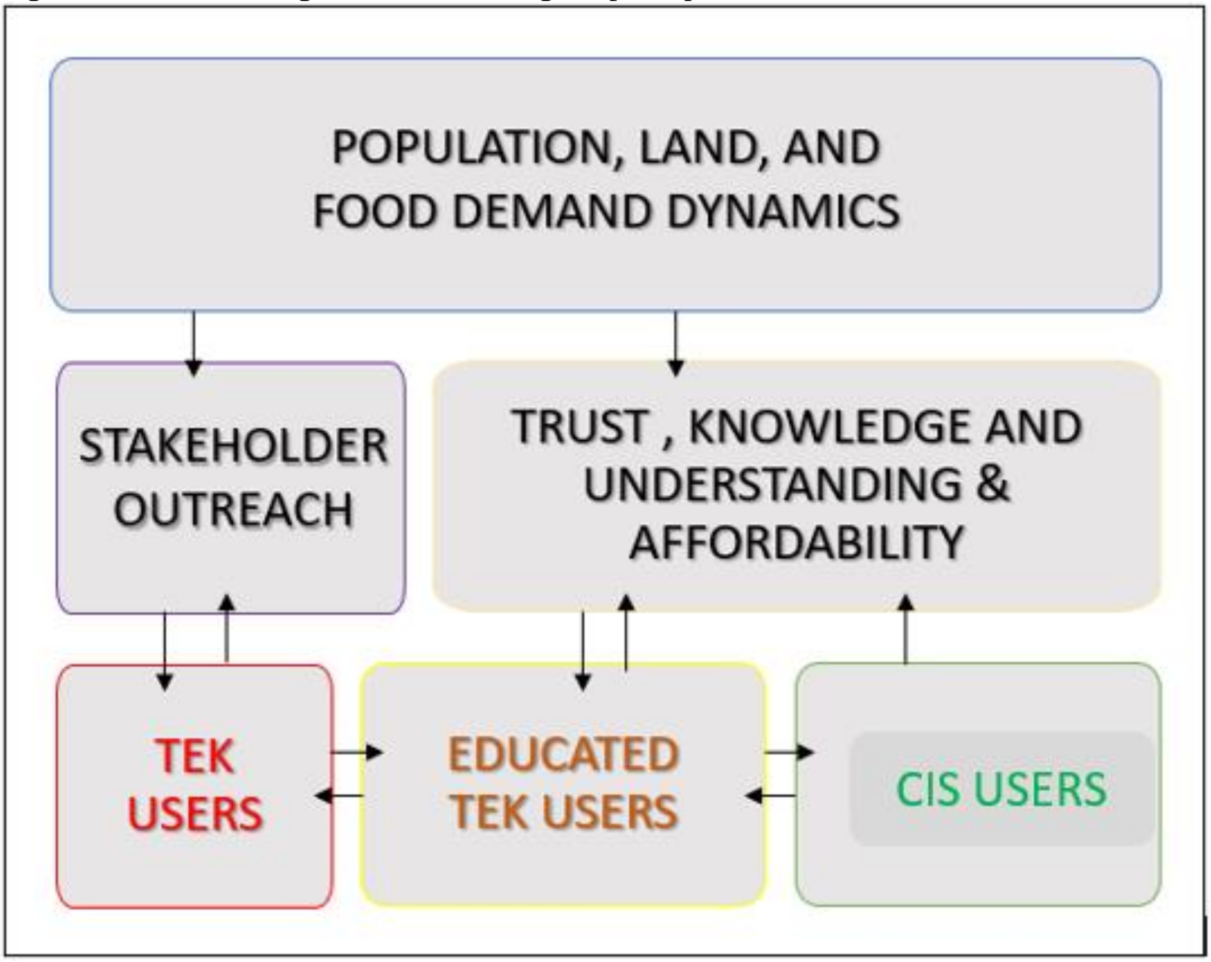
The thesis model aims to provide an understanding of how climate change affects smallholder farmer social-economic welfare inclusive of food availability and household incomes as well as the underlying processes affecting the adoption of climate information services as an innovative agriculture technology for adaptation.

A logical systems framework is developed based on a comprehensive literature review on the adoption and diffusion of new agricultural technologies. Available statistical data is utilized where it is available, to approximate parameter values and assess the model's capacity to replicate past behaviour as recorded in statistical data.

Interaction Between the Different Model Sections

The principal model sections are demonstrated in Figure 1 below to show the typical relationship between the sectors. The rest of this chapter will provide further detail about the model and elaborate on how its formulation centred on academic literature and textual evidence.

Figure 1: Overview diagram demonstrating the principal model sections.



- Traditional Ecological Knowledge (TEK) Users

These are farmers using local and indigenous climate information knowledge and the understandings, skills and philosophies developed by farmer societies because of long histories of interaction with their natural surroundings. For rural and indigenous smallholder farmers, such local knowledge informs decision-making about fundamental aspects of day-to-day life (UNESCO, 2016). This traditional knowledge is also integral to a cultural complex which also encompasses language, systems of classification, resource use practices, social interactions, ritual, and spirituality. With variations and alterations in climate conditions, however, this local knowledge has become redundant and inadequate to realize the full potential of agriculture

- Educated Traditional Ecological Knowledge Users

These are farmers educated about climate information, but relying on indigenous knowledge and personal experience, which they see as more reliable and more appropriate to decision making regarding farming practices.

- Climate Information Services Users

These are farmers who use climate information services in their farm decision making. These farmers have been educated about climate information and have adopted them

- Knowledge and Understanding of Climate Information Services

The variable of knowledge and understanding of climate information services encompasses the proportion of farmers with information and management practices learned from agriculture extension services about application and decision making based on the seasonal rain forecast. Such knowledge includes information about onset days of rainfall, rain amounts expected within the season, floods, temperatures, winds, and ideal harvesting. The inadequacy of traditional ecological knowledge to realize the full yield potential of farm production in turbulent climate conditions makes this knowledge truly relevant for farmer decision making.

- Trust in Climate Information Services

This variable represents the proportion of farmers who trust and use climate information services in their farm decision making.

- Population, Land, And Food Relationship

The variables within this section highlight the interaction between population, land, and agricultural production. Increasing population coupled with land degradation aggravates challenges of crop production. Several research findings support the notion of agricultural increase, considering the population as a driver of development.

- Stakeholder Outreach

The variables within the stakeholder outreach section underline the interaction between farmers education, through government and development organization initiatives as well as farmer interactions.

Model Structure

The model structure expands on the different sections that represent the explanatory nature of the real system. The sections eliminate vagueness on the premise that they represent boundaries beyond which the model might not be applicable. The Bass diffusion model (Bass, 1969) is adopted because it applies in different contexts, including agriculture (Akinola, 1986).

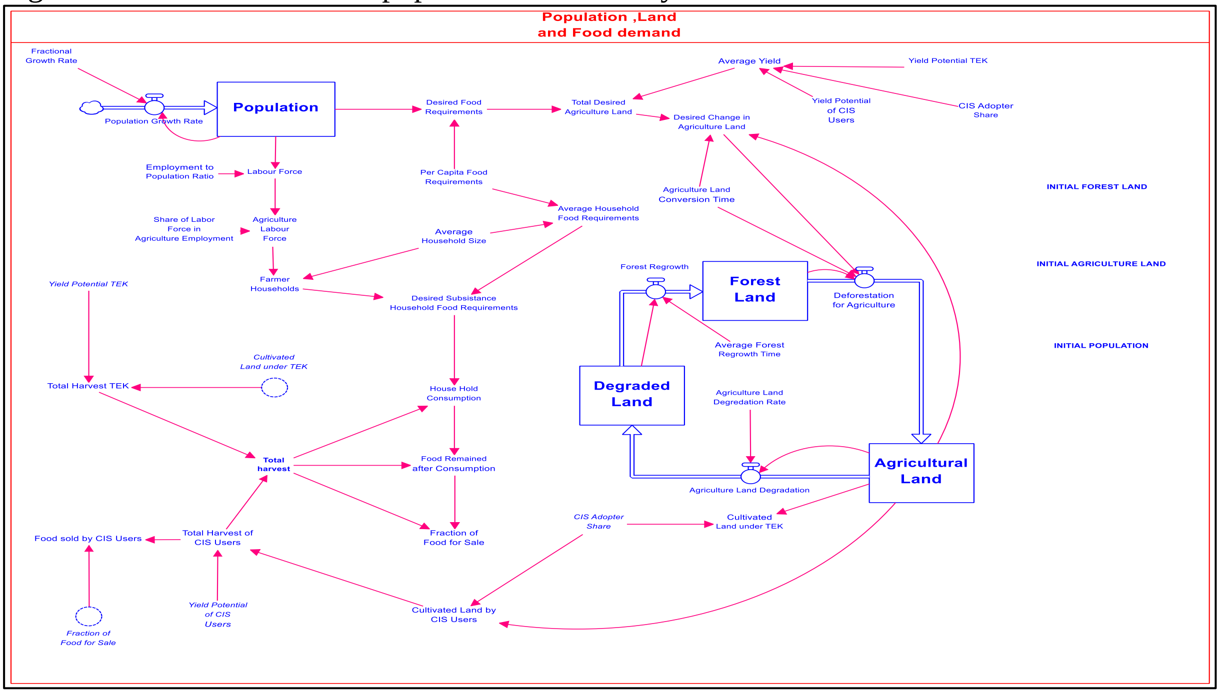
The model draws upon associative concepts that have been implemented or suggested in the literature. An extensive literature study on the diffusion of innovations provides the fundamental structure for modelling how the smallholder farmers may adopt climate information services.

The model structure includes a section representing the population, land, and food demand dynamics and the processes involved in increasing and draining harvest—this, based on the World3 system dynamics model (Meadows, et al., 2004).

Population and Land Dynamics

Land requirements to produce enough food to meet demand driven by population are dependent on the average yield. Increases in average yield reduce land requirements. Traditional methods of weather prediction, however, fall short in increasing yields as farmers are unable to make proper farming decisions for agriculture productivity amidst varying climate.

Figure 2: Model structure for population and land dynamics.



Increment in population results in increased demand for forest land conversion to meet land requirements for settlement and agriculture. The per capita food requirements and the total population determine the desired food requirements. The desired agriculture land which drives land conversion over time is a product of the desired food requirements and the average yield.

Usage of climate information services has the potential of enabling farmers to plan production and improve yields. Such improved yields meet increased food requirements and certainly lessen the problem of transforming forest land into agriculture land. Improved yields also have the potential to make subsistence farmers feed their families as well as improve household incomes.

Agriculture Land Transformation Dynamics

Internal land transformation dynamics for agriculture land involve the conversion of forest land into cultivated agriculture land. This conversion is driven by a gap between available land and land demand, mostly due to the increased need for food production to meet demand. Conversion of land to meet the land demand gap is done over a time denoted as the land conversion time. Agriculture gets degraded with time and flows out into the stock of degraded land to fallow over a while. This fallow period allows the land to turn back to forest land.

- Cultivated land by TEK users

The cultivated land under TEK denotes the proportion of the total land under cultivation that is used by the farmers applying traditional knowledge and means of forecasting to make farm decisions. According to the model, it is derived by distributing the agriculture land by the share of non-adopters of climate information services. Given a large number of traditional knowledge users, the cultivated land under TEK is more prominent in proportion that that under CIS users.

- Cultivated Land by CIS Users

This variable denotes the agriculture land under cultivation by users of climate information services and is obtained by the product of the cultivated land, and the adopters share. Given the high yield potential cultivating using climate information services, harvests from CIS users are higher than those using TEK.

- Total harvest

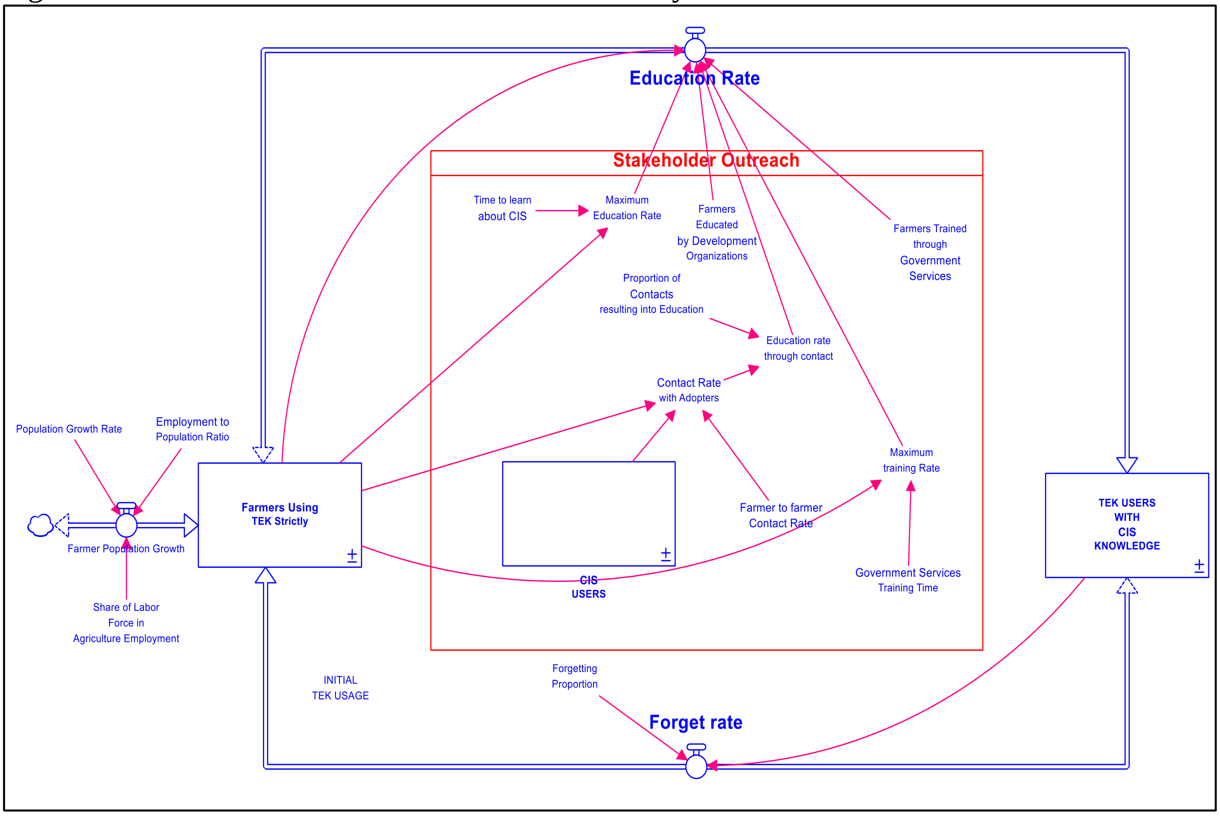
The total harvest variable represents the summation of harvest by both CIS and TEK users. It is distributed into a portion for household consumption based on the main principle of subsistence farming which suggests that the focus of farmers is to satisfy their consumption needs and sell off surplus.

It is also explicitly modelled in this system, the inevitable fact that since the primary source of livelihood of these farmers is subsistence farming, a minimum sale of food must occur in other to purchase what they do not produce and to attend to emergencies.

Stakeholder Outreach Dynamics

The model structure includes a section that explains stakeholder outreach dynamics. The significant dynamic is the movement of farmers from the stock of TEK farmers to the stock of farmers educated about climate information services. This movement represents the desired knowledge change in which farmers may learn the value of climate information services.

Figure 3: Model structure for stakeholder outreach dynamics.



- Education rate

The learning may come about by way of training accomplished and supported by government extension services or by intervening development organizations directly (Reinker & Gralla, 2018). Alternatively, farmers may learn through conversations with other farmers. The rate at which farmers are educated about climate information services is influenced by the frequency and efficiency of the training, and the word of mouth effect. The model's assumption about word of mouth is that it is just as effective as the formal training offered by the government extension services and the development organizations.

- Farmer to farmer contact rate

The contact rate between farmers and the proportion of these contacts resulting in education represent the level of interaction between climate information services adopters and non-adopter farmers to learn about the value of climate information services.

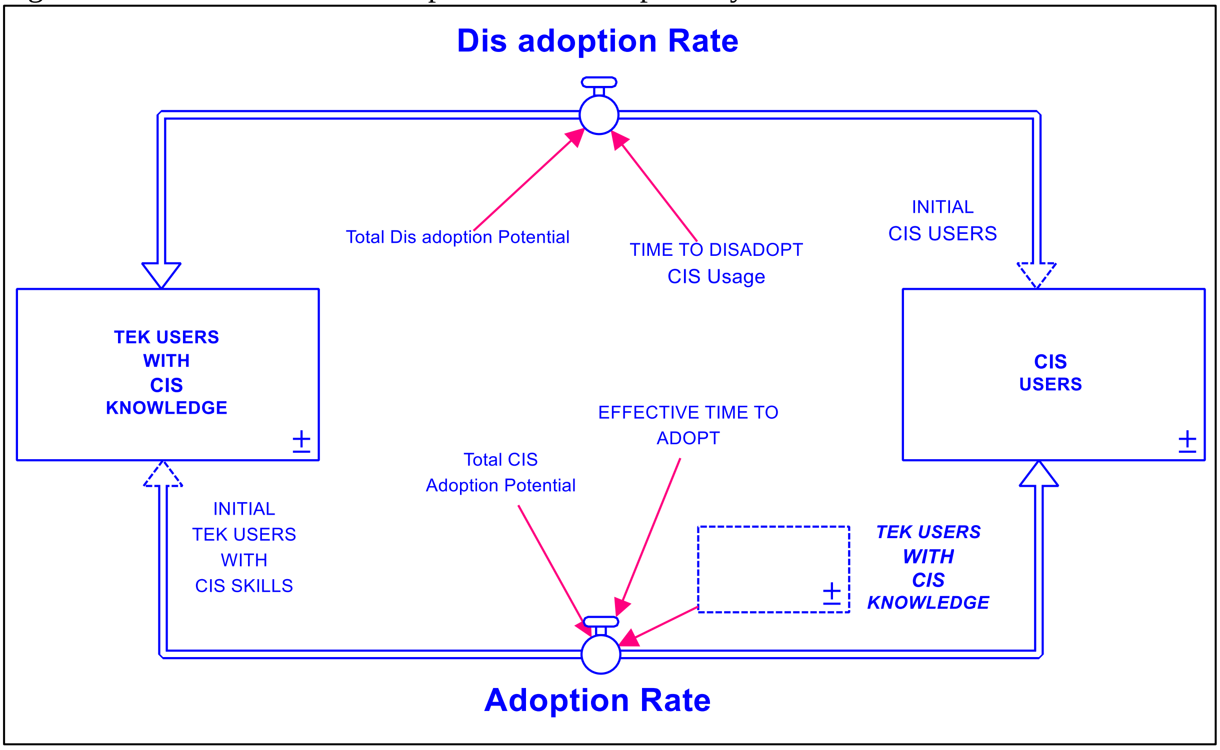
Farmers educated by government extension services and development organizations

These represent the likelihood and proportions of farmers that can interact with the government extension services and development organization that teach about climate information services.

Adoption Dynamics

At the core of the structure lies the farmer decision making section with an adoption rate where farmers decide to take up climate information services as an innovation and a dis-adoption rate where farmers decide to abandon the climate information services. This decision making depends on the evaluation of the relative profitability of climate information services relative to using traditional ecological knowledge.

Figure 4: Model structure for adoption and disadoption dynamics.



The decision making and implementation are characterized by three core elements: trust, knowledge and skill development, and affordability sectors. This structure formulation builds on the bass diffusion model formulation for technology adoption (Sterman, 2000), and formations of Malawi improved maize seed adoption model by (Kopainsky & Derwisch, 2009).

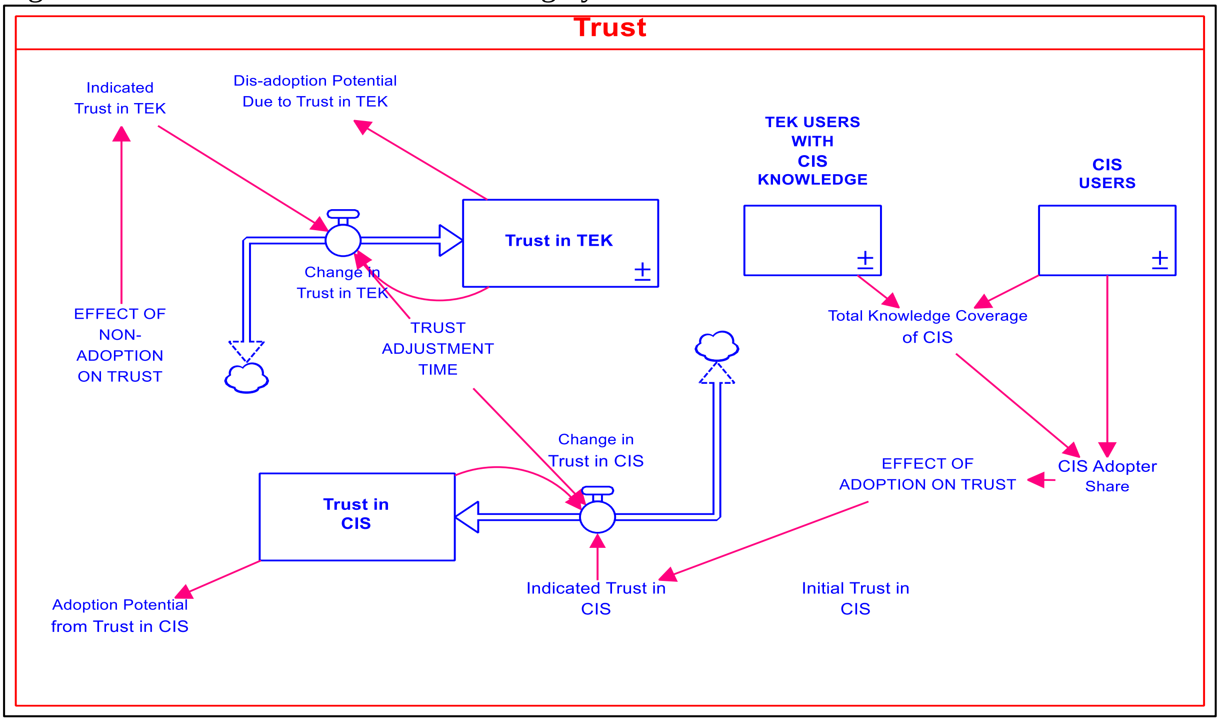
- Adoption Rate

The rate at which educated, TEK users with CIS knowledge become CIS user farmers, or the rate of adoption is given by the adoption potential, multiplied by the TEK users with CIS knowledge over an adoption time frame. The adoption time frame of four years is determined the gradual rollout of training and technology over the length of a representative government and development organization interventions. The adoption potential is determined by the multiplication of CIS Access Affordability, the effect of relative yield on adoption(driven by farmers knowledge and understanding of the climate information services) and the adoption potential from trust in CIS, which represents the motivators for farmers to adopt climate information services.

- Trust

Farmer's perception about the uncertainty and profitability of applying climate information services determines the level of trust that farmers build up.

Figure 5: Model structure for trust-building dynamics.

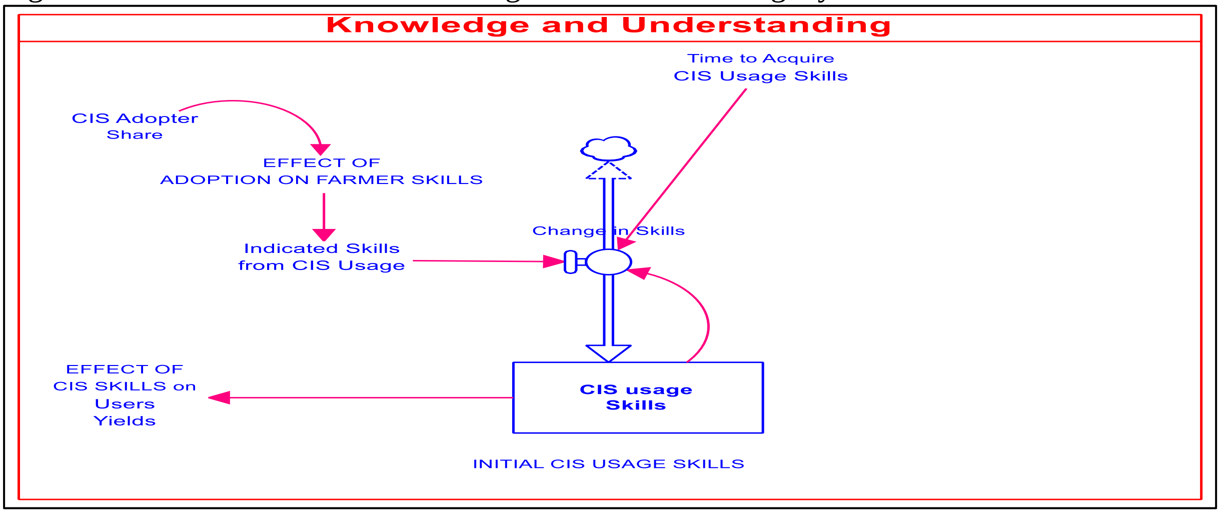


By experimenting with climate information or accessing information from fellow farmers who are experimenting with the services, farmers can build or lose trust in the services.

- Knowledge

Individual learning, knowledge and skills development improves the farmer's ability to implement climate information services. Farmer learning also allows them to make better decisions about climate information services. When smallholder farmers conduct their trials and access information on trial by other farmers, they develop the necessary skills that are required to use climate information services. With the necessary skills, the farmers' revenue potential of adopting climate information can be exploited.

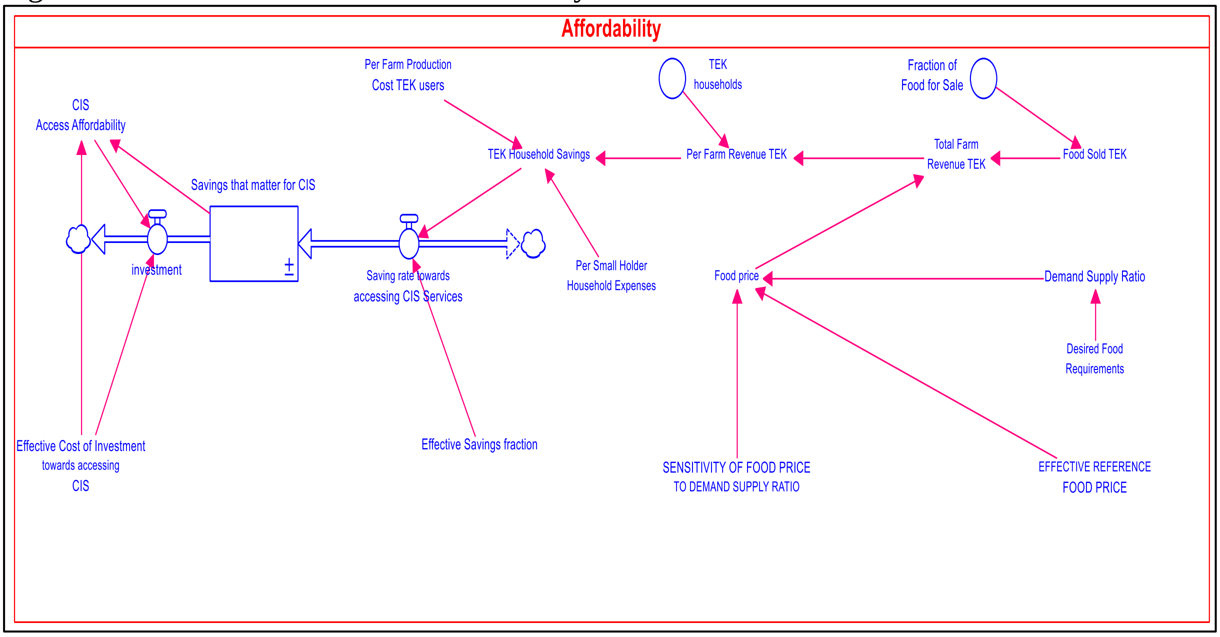
Figure 6: Model Structure for Knowledge and Understanding Dynamics.



- Affordability

Household income from the sale of extra produce plays a crucial role in determining farmer willingness to invest in accessing climate information services. After meeting competing household and farm production needs, farmers tend to save some money from the sale of extra produce. Household needs mostly include healthcare, school fees for the children energy, among others, while farm production needs include the investment farmers incur during production for the next farming season, such as buying inputs such as seeds, fertilizers.

Figure 7: Model structure for the affordability of CIS.

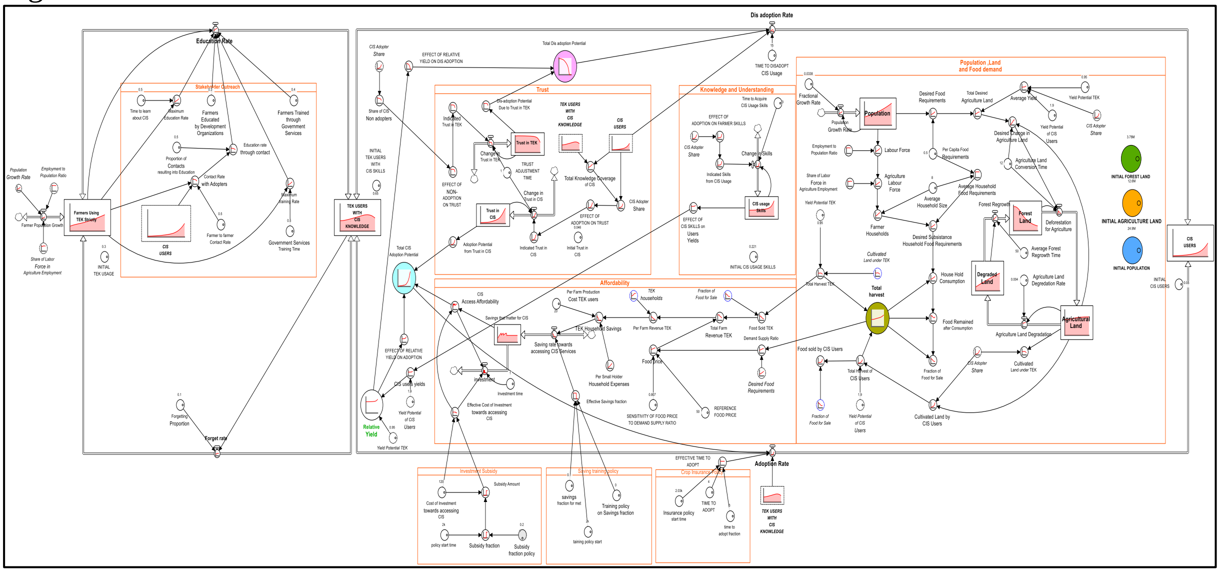


Farmer adoption of climate information services is only possible when the savings that matter for climate information services can meet the investment costs and ensure access affordability. With higher incomes, farmers' budget for climate information and services increases such that farmers can afford to purchase the means of access to climate information service platforms for daily climate information rather than relying on the seasonal forecasts. Declines in household incomes can suggest a drop in adoption rates of climate information services because farmers are unable to afford access.

Table 1: Basic model settings

Variable Name	Value	Comment
Initial TEK users	0.3	The three stocks add up to 1, which represents 100 per cent of the labour force involved in smallholder agriculture
Initial TEK users with CIS knowledge	0.65	
Initial CIS user	0.05	
Initial Trust in CIS	0.05	This represents the percentage of farmers who are initially willing to adopt CIS
Initial Skills in CIS	0.02	
The potential relative utility of CIS		This indicates the factor by which the gross utility of CIS can be multiplied.
Contact rates per year	0.5	

Figure 8: Full model structure



To guide the behaviour analysis of the model, it is useful to understand the cause-effect relationship and interaction between the different variables and parameters that are included in the model. The causal loop diagram in figure 9 helps to simplify the modules of the system.

Figure 9: Full causal loop diagram structure

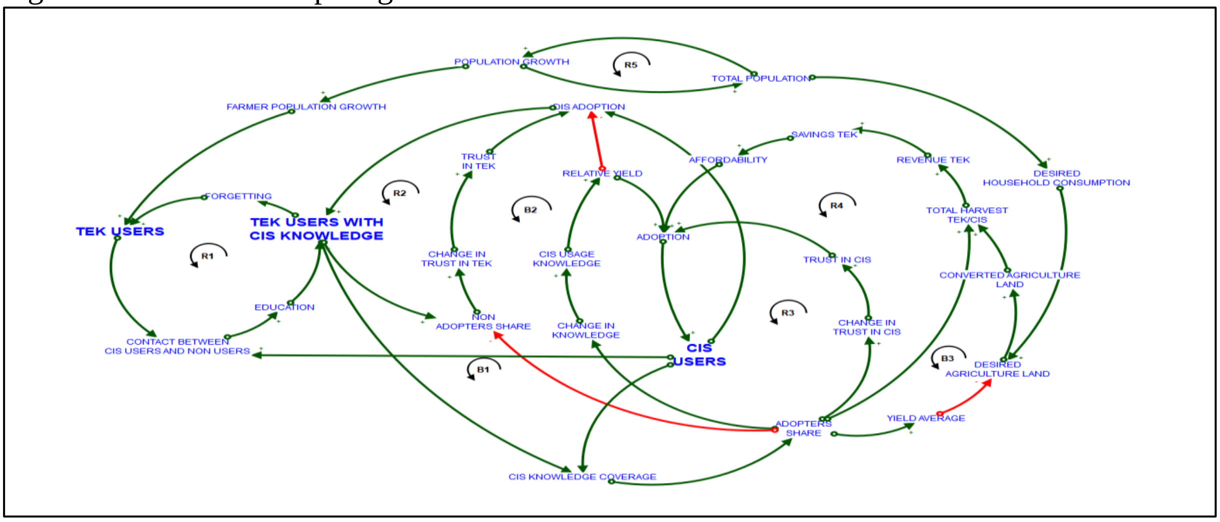
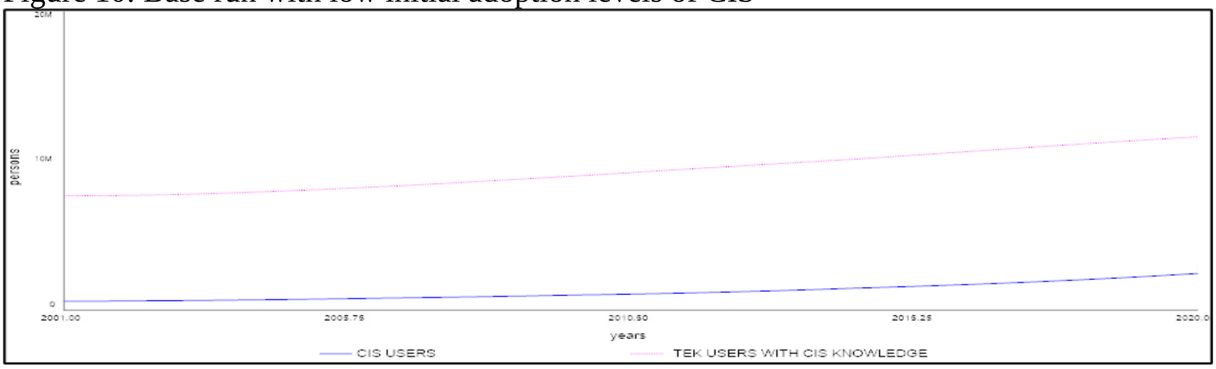


Figure 10: Base run with low initial adoption levels of CIS



Chapter: Model Validation, Testing and Behavior Analysis

Validation

Model validation plays a crucial element of the systems dynamics methodology as it emphasizes the basis upon which the model can be treated as an accurate theory that explains the study subject. It also reinforces the model as a framework for further processing of the methodology. It also allows for model checks and provides the opportunity to gain confidence in the model as appropriate for the purpose the model is developed (Sterman, 2000).

Three types of assessments are conducted throughout the iterative modelling process to continually build confidence in the model based on the guidelines and techniques described by Barlas (1996) and Sterman (2000).

1. Direct Structure Tests
2. Structure Oriented Behaviour Tests
3. Behaviour Reproduction Tests

A partial model analysis is used to evaluate and validate smaller model building blocks as detailed in the previous chapter. This chapter examines the model's precision in the representation of the system under study as described in the previous chapters.

- Internal Validity

The research utilizes data from national reports such as (Poverty Eradication Action Plan (PEAP) 2000 -2003, Uganda Population and Housing Census by the Uganda Bureau of Statistics Main Report 2017, State of Climate of Uganda in 2017 by the Uganda National Meteorological Authority), international reports such as (Fifth Assessment Report of the Intergovernmental Panel on Climate Change – IPCC 2014, Evaluating Agricultural Weather And Climate Services In Africa: Evidence, Methods, and A Learning Agenda) and online interviews with key stakeholders to consolidate the researcher's knowledge of the problem.

1. Uganda National Meteorological Authority (UNMA); F. Luboyera (ED) –3 interviews
2. Uganda National Farmers’ Association (UNFA); D. Nuwamanya (Director) – 1 interview
3. Alliance for Green Revolution in Africa (AGRA); Emelda Sebuufu (Officer) –1 interview
4. OKO Crop Assurance (OKO); Simon Schwall (CEO) – 1 interview
5. One Acre Fund (OAF); Rita Nabirye (Project Specialist) – 1 interview

6. Technical Centre for Agricultural and Rural Cooperation (CTA) B K Addom – 1 interview

Interactions with farmers were not conducted due to COVID-19 international travel restrictions at the time the research study is conducted. However, the stakeholders interviewed provided extensive insights due to their involvement with farmers at different levels.

These methods of data and information accumulation make the model a robust framework for investigating the adoption dynamics of climate information services in Uganda. Peer-reviewed literature sources on agriculture innovation adoption in sub-Saharan Africa are utilized in cases where primary or secondary sources of data specific to Uganda are not available.

- External Validity

Model robustness is assessed by a form of external validation as a process to establish confidence in the reliability and usefulness of the model. This validation is captured as a prerequisite to assess the simulated behaviour of the model with historical data. (Barlas (1996) (Forrester & Senge (1980).

Direct Structure Testing

Direct structure tests assess a model's structure validity by comparison to existing knowledge about the real system (Barlas, 1996). The following direct structure tests are conducted and reported.

a) Structure Verification Test
b) Parameter Verification Test
c) Direct Extreme-Conditions Test
d) Dimensional Consistency Test
e) Boundary Adequacy Test

- Structure Verification Test

The structure verification test determines the model's capability to fit existing knowledge about the real system's structure (Barlas, 1996). A comparison of model relationships and equations with generalized knowledge, relevant knowledge reported in the literature or through engagement with system operatives about the existing relationships in the real system can form a realistic basis upon which the test can be conducted (Barlas, 1996; Forrester & Senge, 1980; Andersen et al., 2012)

In this study, the relationships, and dynamics of the climate information services adoption in Uganda are mapped out via extensive consultation with a range of subject matter experts (UNMA, UNFA, AGRA CTA, OKO, OAF), relevant stakeholders and detailed analysis of data on various aspects of the system. The components representing the adoption process of climate information services as an agriculture innovation were replicated and translated into a causal loop diagram using vast documentary evidence including peer-reviewed sources on agriculture innovations adoption in Uganda and Sub Saharan Africa as documented in the study's theoretical background.

The elements and interconnections of the causal loop diagram (Figure 9) form the foundation for the variables, stocks and flow formulations and new relationships in the system dynamics model. Critical factors regarding the processes that inform adoption and diffusion, such as trust in climate information services, knowledge and understanding of the usage of climate information services for improved yields, as well as the relationship between TEK household income levels and affordability to adopt are indicated as drivers of adoption and diffusion.

The resulting product is a particularly useful reflection of the current understanding of the climate information services among smallholder farmers in Uganda. It can, therefore, be deemed valid given its explicit formulations, hypothesized causal relationships and strong foundation in published sources.

- Parameter Verification Test

Parameter verification testing determines whether the model's constant exogenous parameters and variables are consistent with significant descriptive and numerical knowledge of the real system, and their values lie within plausible numerical ranges (Barlas, 1996). The correlation between the model parameters and existing knowledge of the system can be considered sufficient to provide confidence in conceptual parameter validity.

All parameter values were estimated based on actual data where possible. Where such data was insufficient, estimations based on national data were made. Model effects values are estimated based on literature about the non-linearity relationships between adopter shares and knowledge building on trust and relative utility, respectively, for agriculture innovations (Kopainsky &

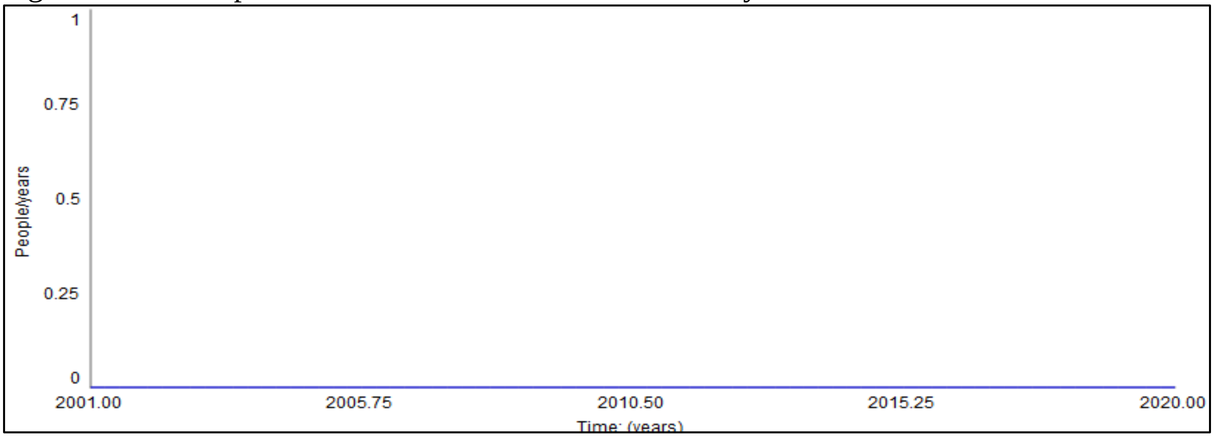
Derwisch, 2009). Additional, simplifying assumptions about specific parameters to suit the model-specific model setting and ensure consistency needed to be made. These were approximated experimentally by running multiple simulations to investigate parameter values that produced the most logical behaviours. For the model, statistical parameter validity can be assumed to be strongest when based on data, robust when estimated through model experimentation and stable when based on reasonable and supported assumptions.

- Direct extreme-conditions test

The direct extreme-conditions test evaluates the response of the model to extreme settings of each model parameter against how the real system is expected or known to respond (Forrester & Senge, 1980). Model parameters were altered to extremely low or extremely high values to check if computational errors would be generated.

For this model, the extreme condition was evaluated by turning off the affordability of climate services. With no affordability, there is zero adoption of climate services among smallholder farmers.

Figure 11: Development of cis users when the affordability of cis is zero



The structure of the model can be considered sufficiently robust to extreme conditions as no errors were detected.

- Dimensional Consistency Test.

Dimensional consistency test confirms the model units' mathematical consistency of the equations both the left- and right-hand sides (Barlas, 1996) The software used to build the model reports no error warning when checked for unit errors and hence confirms overall dimensional consistency. The dimensional consistency test also checks that there is no introduction of variables to force the model to function. All model variables and their units are equivalents or are acceptable with real-world units.

- Boundary Adequacy Test

The boundary adequacy test determines whether all fundamental structures necessary for realizing the purpose of the model are endogenized (Sterman, 2000). The purpose of the research model is to provide answers to the research question listed in the introduction chapter.

This purpose infers that the model functionality must be adequate for identification of the structural factors of the low adoption rates of climate information services among smallholder farmers in Uganda(Objective 1 and 2) and explore interventions to address the limitations in adoption rates of climate information services (Objective 2). The sections included in the model identify interactions between population, land use, food availability, consumption, household income, stakeholder outreach systems to determine the changes among and between them that influence the adoption of climate information services among smallholder farmers in Uganda. The model boundary can be considered sufficiency adequate for its purpose. However, the model can better reflect reality with inclusion of explicit structures that represent additional existing agricultural and ecological policy known to influence farmers' households decisions about the adoption of improved agriculture innovation practices via a variety of socio-economic influences and these highlight areas for further refinement in potential future work.

Sensitivity Analysis

The model is validated for both numerical and behavioural sensitivity by adjusting numerical values to investigate if there are significant changes in the modes of behaviour when assumptions upon which the model is built are changed over a range of uncertainty (Sterman, 2000). This testing identifies model parameters which might be highly sensitive in, and these are compared to the real system's behaviour (Barlas, 1996).

- Stakeholder Outreach Sensitivity Testing

The adoption rate's sensitivity to stakeholder outreach is assessed by adjusting the values in farmer training time as well as the fraction of farmers trained—variations in the training times between 0.5 to 1 year.

Figure 12: Sensitivity of adoption rate with variations cis training time

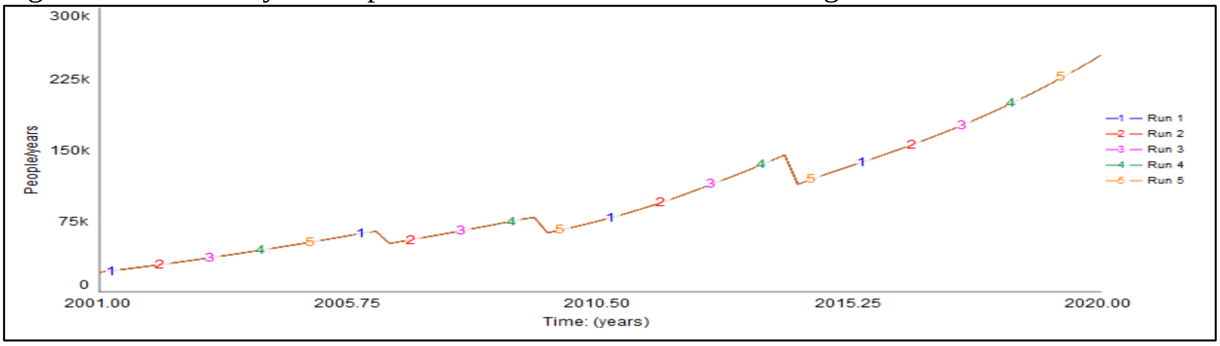


Figure 13: Sensitivity of adoption rate with variations in the fractions of farmers trained

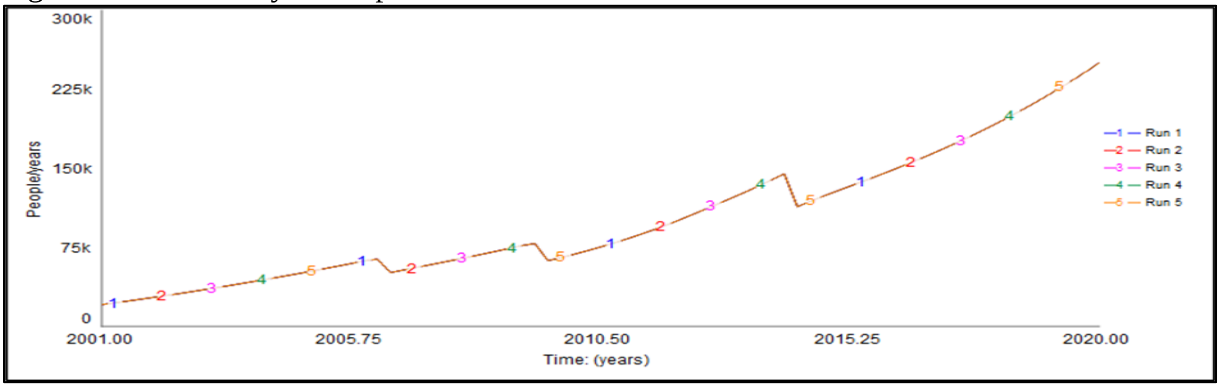


Figure 12 and 13 show that there are no variations in adoption rates with changes in the fraction of farmers trained and the time taken to train the farmers.

Considerable variations are however observed in the education and adoption rates with variations in the farmer to farmer contact rates; Figure 14, as well as the proportions of contacts resulting into an education rate. Increased contact rates within farmers simply increase the pool of farmers educated about climate information services but inversely affect adoption rates.

Figure 14: Sensitivity of educated farmers on variations in training time to learn about CIS

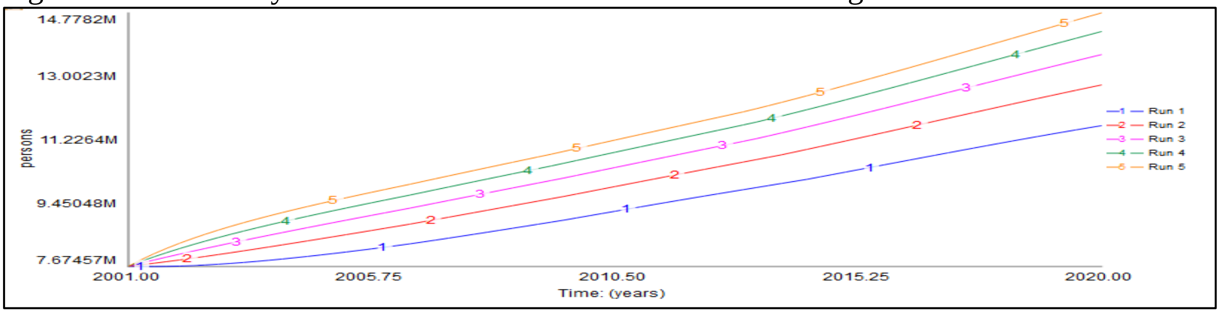
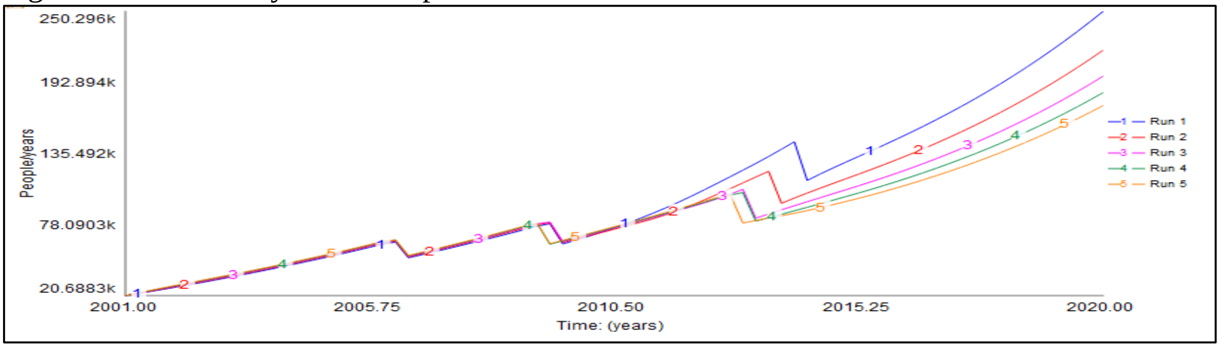


Figure 15: Sensitivity of the adoption rate with variations in farmer to farmer contact rates



Stakeholder outreach has only got implications on the adoption by increasing the pool of educated farmers.

Figure 16: Sensitivity the adoption rate with variations in trust adjustment time

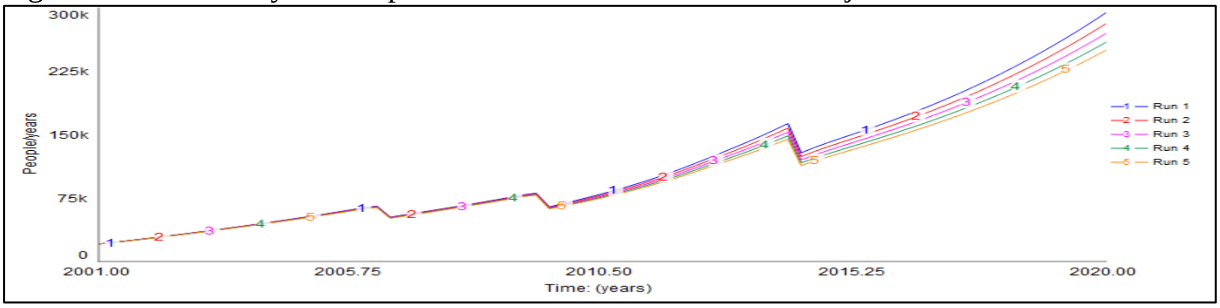
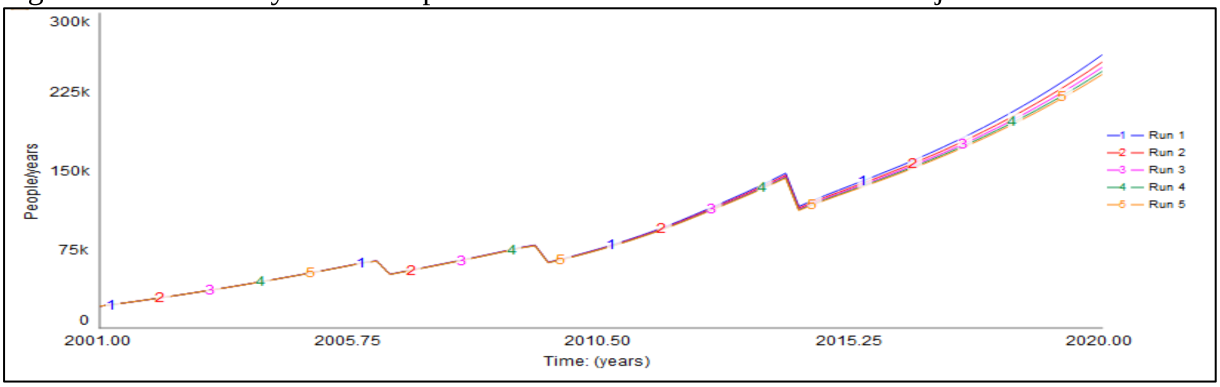


Figure 17: Sensitivity of the adoption rate with variation in CIS skills adjustment time



Model behaviour analysis

Education and forgetting

The model behaviour is analyzed per section. It is started in equilibrium with the initial values for the different stocks of farmers using TEK, Farmers using TEK but having knowledge about climate information services, and farmers using climate information services. These are based on estimated values from literature to fit the system symptoms. According to Figure 18, these stocks remain consistent throughout the model simulation run.

Figure 18: Stock variations when in equilibrium

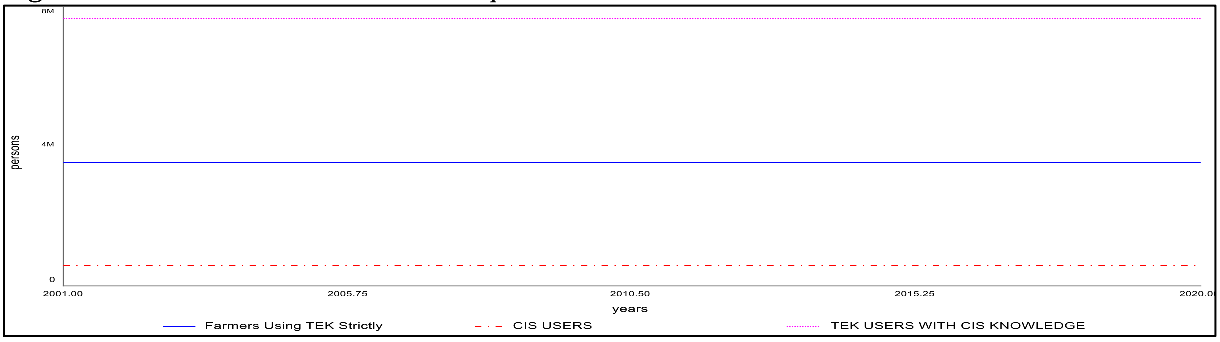
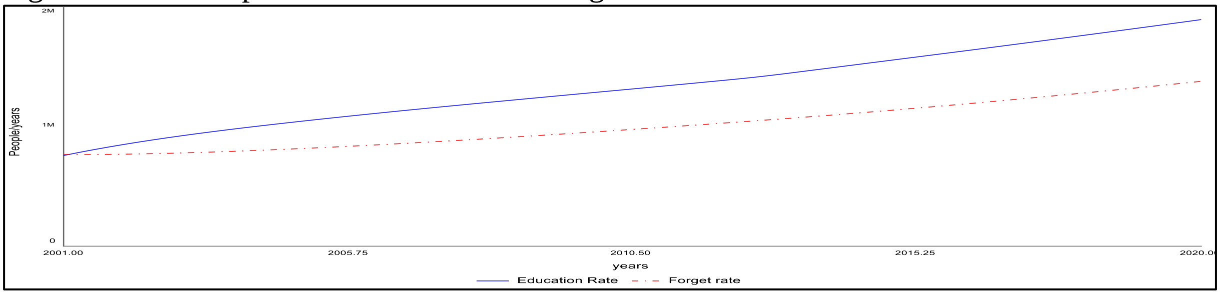


Figure 19: Development of education and forget rates



Though the two rates (Education and Forgetting) start at similar values, Figure 19 highlights that there are more people educated than those who forget. This implies that there will be more people who know about climate information services than those who do not know about the services.

Knowledge about climate information services does not necessarily translate directing into the adoption of these services. The stocks of farmers using TEK strictly and those using TEK with knowledge of Agro-met advisory services show an increment.

The stock of Farmers using TEK is increased by:

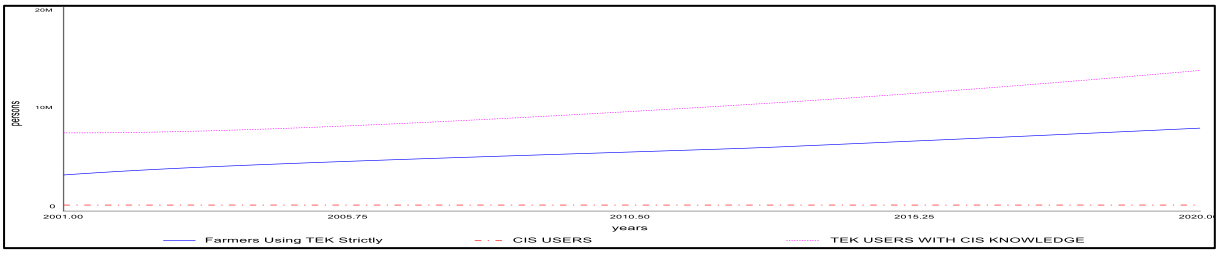
- Farmer Population Growth = Population Growth Rate*Employment to Population Ratio*Share of the labour force in agriculture employment.
- Forget rate = Forgetting Proportion* TEK users with CIS knowledge.

These two rates take into consideration the new farmers because of population growth, and farmers who are educated about CIS but end up forgetting.

By turning on population growth and education and forgetting rates, these stocks experience variations in their stock levels except the stock of climate information services users see Figure

20. This implies that the education of farmers does not necessarily affect the adoption process directly but increases the stock of potential adopters.

Figure 20: Farmer stock variations (population growth, education and forgetting rates are on)



Adoption and Dis-adoption

The Adoption rate and Dis-adoption rate of Agro-met advisory services increases or decreases the stocks of Farmers using TEK but having knowledge about climate information services, and Farmers using climate information services. This is done through the total adoption potential and total dis-adoption potential, over 4 and 15 years for each of the rates, respectively.

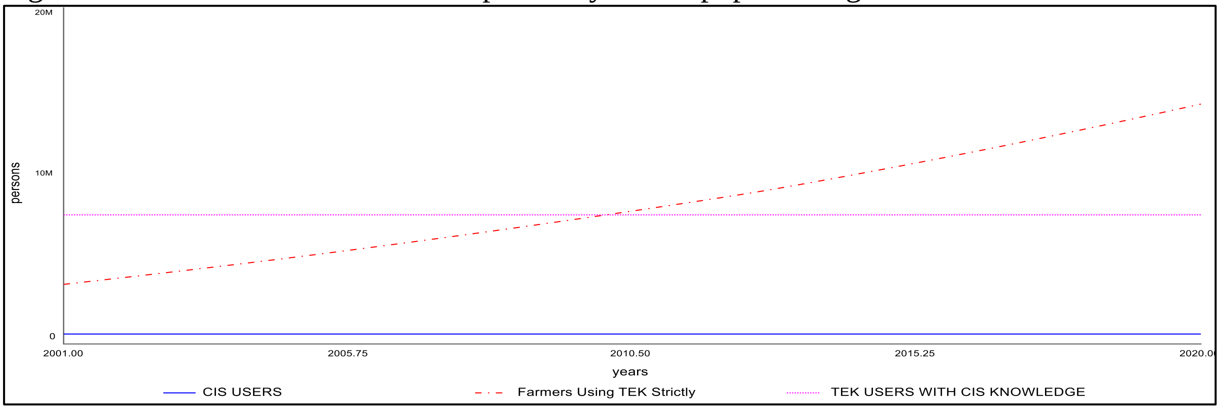
- Adoption rate = TEK users CIS knowledge* Total adoption potential /time to adopt
- Dis-adoption Rate = Total Dis adoption Potential* CIS users / time to dis adopt

The Total adoption potential is influenced by the trust in climate information services, affordability of access, as well as the knowledge and understanding of using climate information services which determines the level utility of climate information services by affecting the relative yield.

- Total adoption potential = effect of relative yield on adoption *Adoption potential from trust in CIS * CIS access affordability.
- Total dis adoption potential = Dis adoption potential due to trust in TEK * Effect of relative yield on dis adoption.

By turning off the education, forgetting rates, adoption, and dis-adoption rates, but keeping the population growth on, the stocks of total farmers, as well as Farmers using TEK strictly, will grow, but there will not be any change in the other stocks as in Figure 21.

Figure 21: Farmer Stock variation dependency on the population growth rate



Turning on the adoption and dis adoption while the knowledge, trust in CIS and Affordability turned off. There is a small increment in the number of Farmers using TEK but educated about CIS. This is due to the dis adoption of CIS by some farmers due to trust in TEK.

Figure 22: Farmers using TEK but educated about CIS

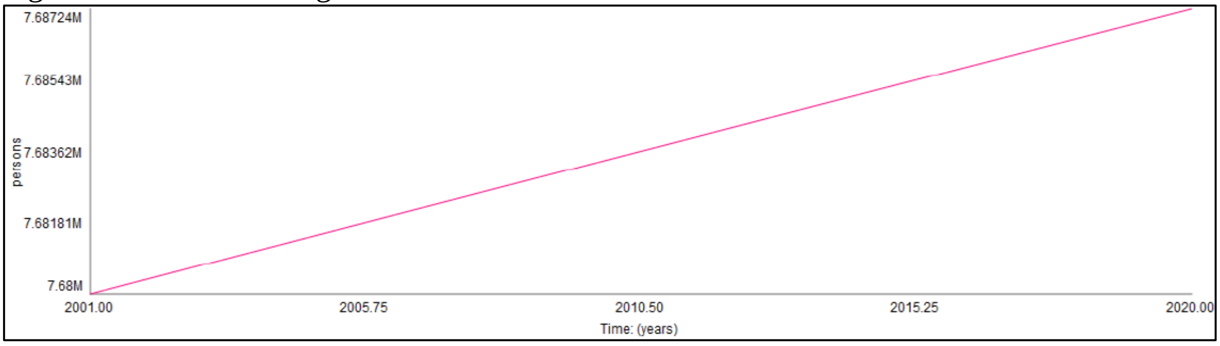


Figure 23: Total Adoption potential- Trust and knowledge turned on, but 0 affordability

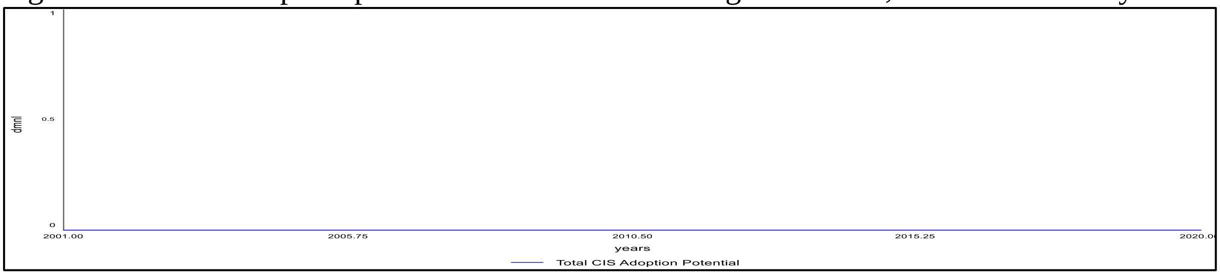


Figure 24: Total adoption potential- Affordability of CIS access turned on but 0 trusts in CIS

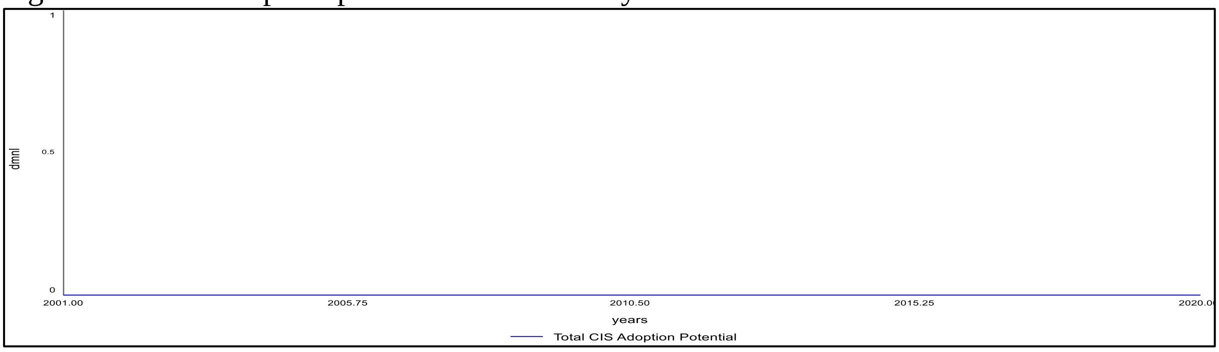
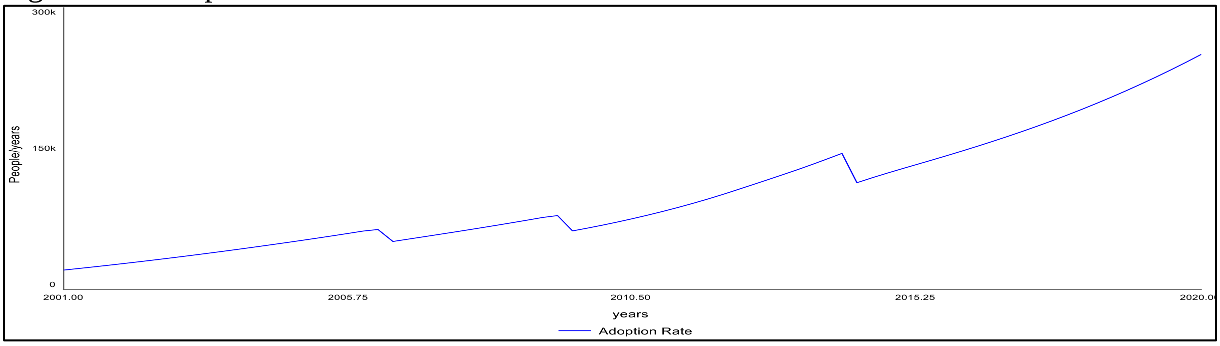


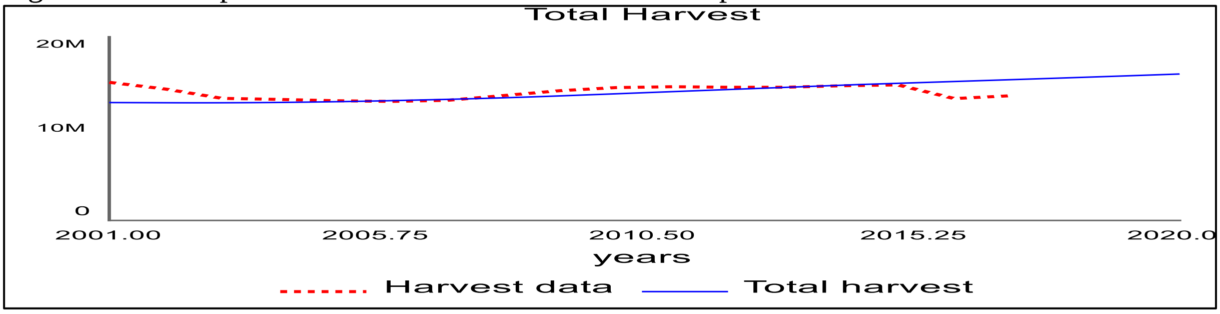
Figure 25: Adoption rate with business as usual



- Total Harvests

The system exhibits variations in total crop harvests that are like to reference data. These disparities can be attributed to inconsistent weather patterns which at times impact soil moisture content, leading to different yields. Seasonal shifts and changes in temperature and precipitation patterns have a severe impact on agricultural production and other livelihood activities.

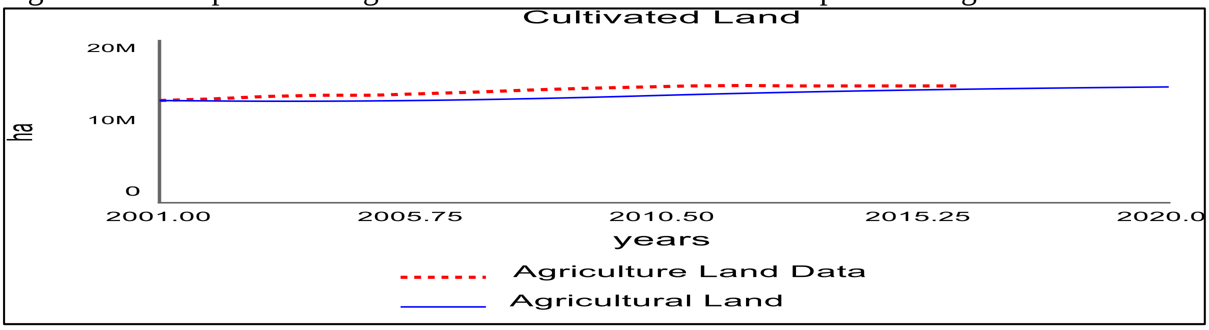
Figure 26: Comparison of harvest data with the model produced total harvest



- Cultivated Agricultural Land

Increment in cultivated agricultural land can be attributed to many socio-economic and policy-related factors, such as population pressure; poverty; agricultural commercialization; high purchased input costs; land tenure relationships; and general policy reforms.

Figure 27: Comparison of agriculture land data with the model produced agriculture land



Chapter: Policy Design and Analysis

After examining the critical behaviour patterns generated by the model, the focus is turned towards using the model for the analysis of strategies to foster the adoption and diffusion of climate information services among smallholder farmers in Uganda. The explanatory model highlights that it is crucial to approach the socio-economic aspects that determine farmers' adoption decisions of climate information services as entry points for enhancing adoption.

Policy Design Space

The policy design section discusses options that can alleviate the problematic low adoption of climate information services among smallholder farmers in Uganda. Policies to stimulate the adoption of climate information services among smallholder farmers can affect different determinants of adoption. Examples of typical policies to stimulate adoption and diffusion include the following:

- Market Instruments: Subsidies and price supports have a propensity to increase new technology’s relative profitability and thus improve the utility of climate information services
- Microcredits: Microcredits to smallholder farmers affect the farmers’ capital availability, and this can increase the utility of climate information services.
- Memberships in farmer groups: The positive influence of farmers’ organizations highlights the continued role of social capital in climate information adoption.
- Participation in a safety net program enhances farmers adoption of climate information services by cutting down on the adoption time.

The system variables affected by the identified policies to stimulate the adoption of climate information services are summarised in table 2.

Table 2: System variables affected by policies to stimulate adoption of CIS

Policy	**Affected System Variables**	**Duration of Policy**
Market Instruments	Affordability	10years
Microcredits	Affordability	10years
Memberships in farmer groups	Trust, Knowledge, and utility	10years
Safety net program	Time	10years

The model variables affected by the identified policies to stimulate climate information services adoption are summarized in table 3 below

Table 2: System variables affected by policies to stimulate adoption of CIS

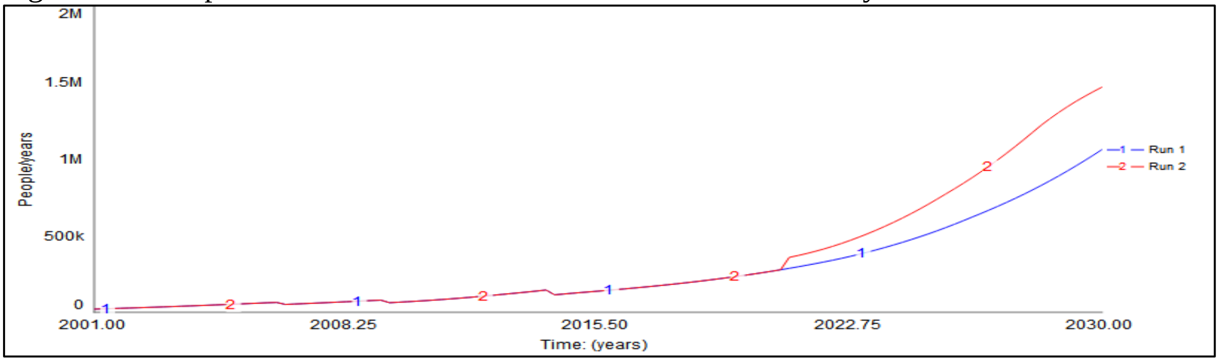
Policy	**Affected Model Variables**	**Duration of Policy**
Market Instruments	Cost of Investment	10years
Microcredits	Cost of Investment	10years
Memberships in farmer groups	Trust, Knowledge Adjustment Time	10years
Safety net program	Adoption Time	10years

Policy Analysis Results

Subsidizing the cost of investment to access climate information services

Adoption is highly influenced by affordability. Enabling smallholder farmers' ability to afford access to climate information services and trust-building in scientific climate information is necessary. Without enabling farmers affordability of the climate information services, the effectiveness of stakeholder approaches such as farmer training and education orientated intervention is extremely low. The cost of Investment is subsidized beyond 2020 by 10-20 per cent in and the results shown by figure 30.

Figure 28: Adoption rate with the subsidized cost of investment beyond 2020

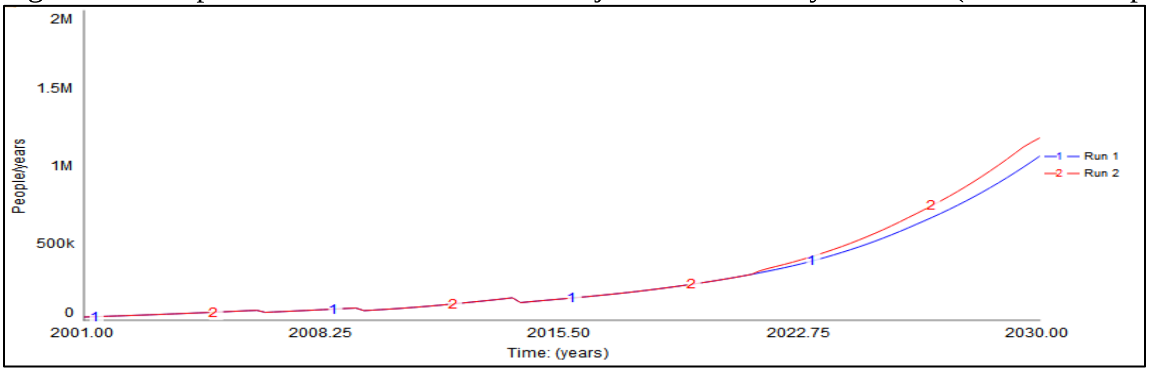


- Run 1 shows the adoption rate with business as usual
- Run 2 shows the adoption rate with a subsidized cost of investment (0.2)

Encouraging memberships in farmer groups to improve on the farmers' trust

Farmers' trust in climate information services and their perceptions about previous climate information services consistency and the knowledge to fully utilize climate information services for improved production can affect the level of adoption of climate information services. The trust adjustment time is varied between 0.5 and 1 year to observe the changes in the adoption rates in figure 31.

Figure 29: Adoption rate with reduced trust adjustment time beyond 2020 (Farmer Groups)



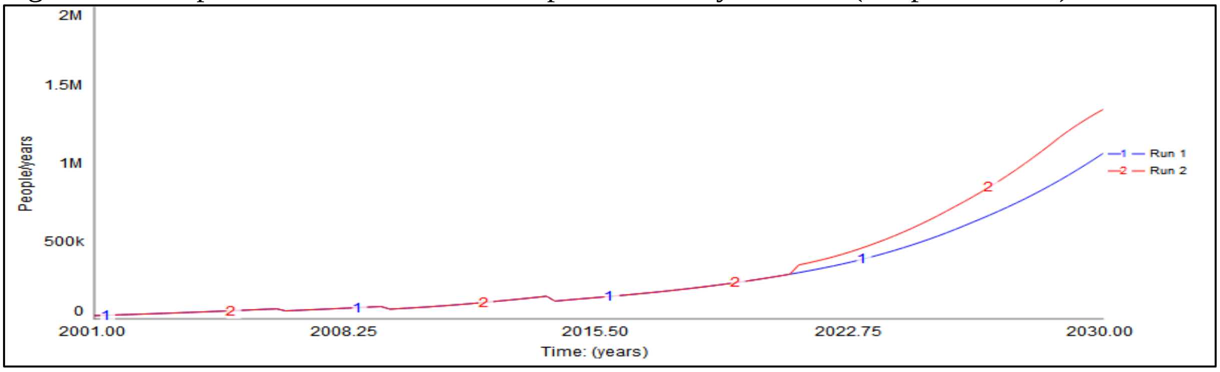
- Run 1 shows the adoption rate with business as Usual
- Run 2 shows the adoption rate with a reduced trust adjustment time (0.5 years).

Providing farmers with crop insurance to reduce adoption time

Diffusion of climate-related information and measures that expedite this diffusion can have a positive effect on adoption. It is imperative to note that risk factors affect the degree of adoption since most smallholder farmers are usually risk-averse and tend to adopt innovations that can improve their farm output in the short run.

Reducing the uncertainty associated with climate information services can be one measure that can provide farmers with safety nets to fall back to in case climate information services are not adequate. Crop insurance reduces financial risk and helps farmers to maintain, expand, and increase the efficiency of their farms, increases investment in production assets and enables the farmers to recover after an erratic weather disaster. Providing farmers with crop insurance provides such a safety net to allow farmers to try out climate information services as an agriculture innovation and thereby shortening the adoption time increases climate information services adoption. Variation in the adoption rates with a reduction in adoption time is shown in figure 32 below.

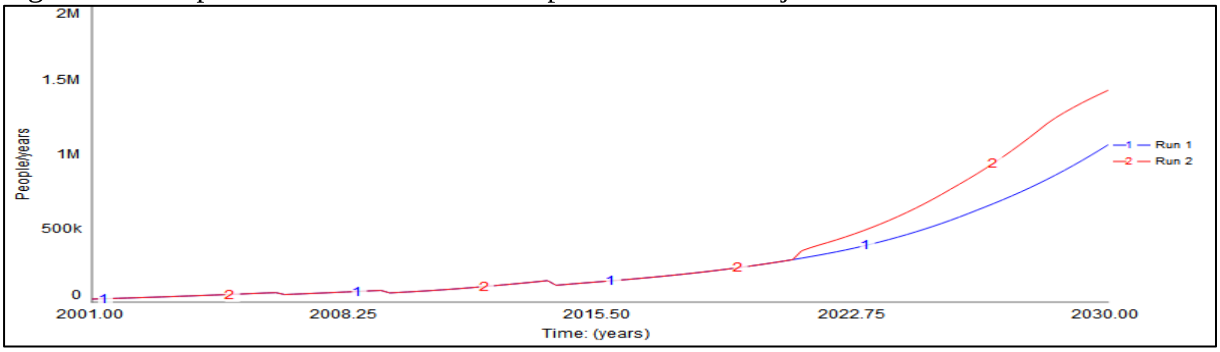
Figure 30: Adoption rate with reduced adoption time beyond 2020(Crop Insurance)



- Run 1 shows the adoption rate with business as usual
- Run 2 shows the adoption rate with a reduced adoption time (3 years).

A combination of reduced adoption times and trust adjustment times

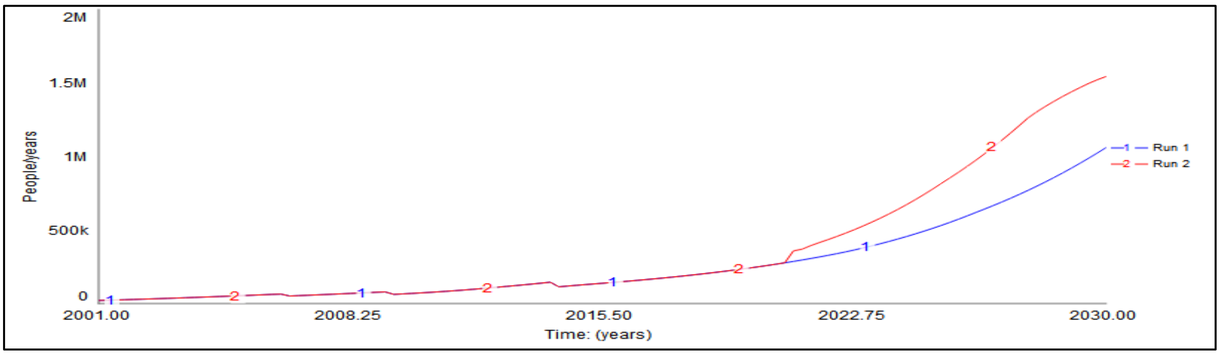
Figure 31: Adoption rate with reduced adoption time trust adjustment time



- Run 1 shows the adoption rate with business as usual
- Run 2 shows the adoption rate with a reduced trust adjustment time (0.5 years) and adoption time (3 years).

A combination of subsidized cost of investment and shorter trust adjustment time

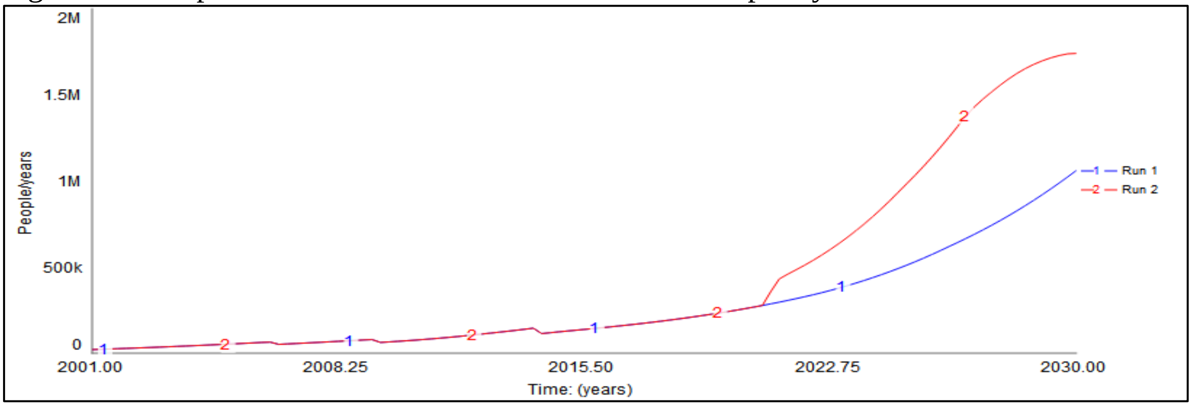
Figure 32: Adoption rates with the subsidized cost of investment and short trust adjustment time



- Run 1 shows the adoption rate with business as usual
- Run 2 shows the adoption rate with a subsidized cost of investment in accessing CIS (0.2) and shorter trust adjustment time (0.5 years)

Combining the three interventions (reduced adoption time (crop insurance) reduction in the trust adjustment time (FGM) and reduction in the cost of investment(subsidy).

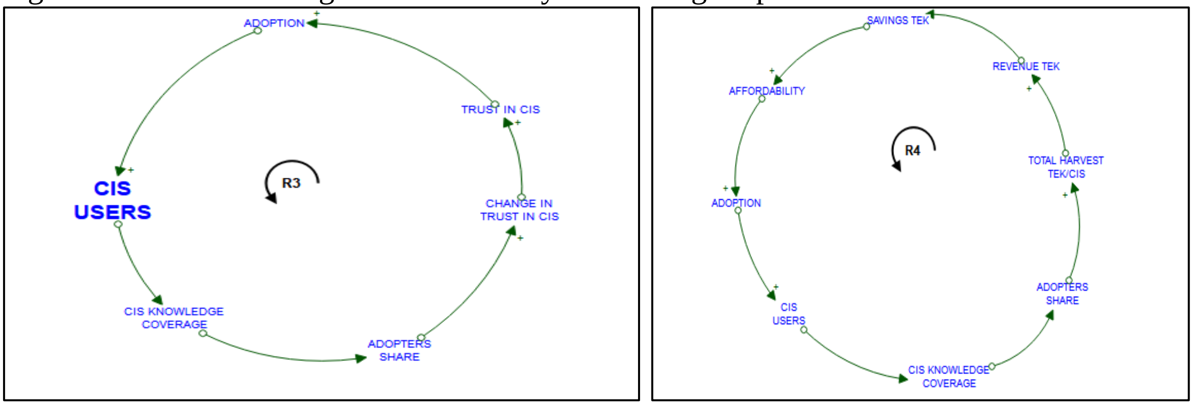
Figure 33: Adoption rates with a combination of the three policy interventions



- Run 1 shows the adoption rate with business as usual
- Run 2 shows the adoption rate with a combination of interventions.

It is particularly important to note also that the combination of the three policy interventions together has the most significant benefit. This importance can be attributed to the interaction of a combination of several reinforcing mechanisms within the model the social learning loop R3 and the affordability loop R4

Figure 34: Social learning and affordability reinforcing loops.



Improving the levels of social learning as well as the affordability of accessing climate information services has the potential to stimulate adoption. Trust building components of farmer interactions in groups are sufficient to stimulate adoption. Farmer access to income can allow smallholder farmers to afford access to climate information services.

Chapter: Conclusions

Based on the system dynamics model about the adoption of climate information services in Uganda, the study finds that intervening in several parts of the adoption process is essential to improve the impact of the interventions.

From the model behaviour review, it can be concluded that although technology-related attributes such as the potential yield significantly influence adoption, it is the socio-economic aspects that determine farmers' adoption decisions of climate information services. From the policy analysis, it can be observed that, in the short run, it is necessary to subsidize climate information services costs to improve adoption to a point when farmers have accumulated income enough to be able to pay the actual cost of climate information services.

Farmers must afford as well as trust climate information services. Farm income and savings are likely to increase the adoption of climate information services. This is mainly because income helps in solving farmers' liquidity constraints in agricultural production which helps the farmer to afford access to climate information services.

Social learning was also found to positively influence the adoption of climate information services probably because this learning is believed to reduce the amount of complexity that farmers perceive in a climate information services thereby increasing trust and CIS adoption.

The reluctance towards climate information by farmers due to trust in TEK can slow down the adoption of climate information services. This reluctance can be in cases where trust in CIS depreciates too quickly for social learning to support individual learning and therefore, adoption.

Overcoming reluctance towards the adoption of climate information services can be exceedingly difficult and costly to overcome. Providing farmers with safety nets and incentives that help to increase trust in climate information services can encourage farmers to adopt climate information services.

Crop insurance is one such safety net that can encourage farmers to adopt climate information services.

Discussion and outlook

The main objective of the study was to answer the following questions

1. What factors influence smallholder farmer adoption of climate information services in Uganda?

In the system studied, it is found that adoption improvement is constrained by critical elements (affordability and trust) without which the other interventions have little effect. The inability of farmers to afford innovative agriculture interventions such as climate information services can hinder farmer adoption of technology in Uganda. Additionally, intervening with trust improvement only by reducing the trust adjustment time has the least effect.

2. What are the causal feedback mechanisms within the factors influencing smallholder farmer adoption of climate information services in Uganda?

The study's simulation runs identified feedback mechanisms, in which the more objective elements of adoption prevail and feedback mechanisms in which social dynamics dominate the adoption of climate information services. Climate information services adoption decisions are driven more by objective evaluations such as affordability in the initial stages of adoption when the share of the farmers who adopt the climate information services is still low. As the number of adopters increases, the social dynamics within the system tend to influence the adoption processes.

The success of stakeholder training-related interventions is limited by constraints on farmer adoption, such as demand for agricultural innovations. Farmers demand for climate information services or other agriculture innovations is necessary for governments, and development organization to advance these services.

3. What effective policies can improve the adoption of climate information services in Uganda?

Effective policies to stimulate the adoption and diffusion of climate information services in Uganda depend on investments in multiple parts of the adoption process simultaneously, which led to more significant improvements than investing in each individually. Analysing the system structure, as captured in the model, helps explains why intervening in multiple parts of the adoption process improves the impact of the interventions. It is necessary to jumpstart multiple reinforcing loops, and farmers must be able to afford innovations as well as learn the value of using innovations in order to generate demand for them.

The findings from the study also have suggestions for designing strategies for adoption of agriculture innovations in Uganda. Although the conclusions from this research study cannot be used to identify leverage points in other systems that might be different in structure, it is, however, possible to infer from the study's findings and suggest that significant leverage points for policies that improve adoption of agriculture innovations among smallholder farmers may be identified by locating crucial reinforcing loops that can be jumpstarted in order to encourage adoption and diffusion of these innovations.

Population growth has also been identified in this study as the main deterrent to the adoption of agricultural innovations such as climate information services in Uganda. With surges in population, farmers are unable to save enough money after catering for household needs and farm needs.

Future research can explore interventions that enhance the adoption of agriculture innovations through family planning methods among smallholder farmer for improved saving ability.

Transferability of research model to other countries and other agriculture innovations

The insights produced in this thesis about the adoption and diffusion of climate information services among smallholder farmers in Uganda can have implications for countries with conditions similar to Uganda. The work complements literature on climate information services adoption and usage while recognizing existing works on the dynamic aspects of adoption and the socio-economic aspects that determine farmers' decision-making trends.

The research also offers implications that can be transferable to other agriculture innovations where users' adoption and diffusion is key for impact, such as the preliminary conditions, any underlying feedback mechanisms, and how policies and interventions can be designed and verified using system dynamics simulation models.

The research study's contribution is therefore relevant to policymakers, development organizations, private sector investors, and suppliers of innovative agriculture solutions since it highlights the different opportunities and risks of using different adoption incentives to achieve the desired results.

Perhaps most importantly, this study highlights that whereas agriculture innovations can harness the power of social learning's reinforcing mechanisms to improve adoption of agriculture for enhanced productivity, this process can be limited by the affordability of these innovations by smallholder farmers. This can impede the speed and spread of the desired results.

One other interesting insight that is not usually mentioned in literature is the role that population growth plays in determining innovation adoption by affecting farmer incomes and savings and overall affordability of new agriculture innovations.

Suggested recommendations for how the research study's simulation model and insights can further be improved upon include:

The model can be used during efforts that involve multiple stakeholder participatory engagements for agriculture development. In such settings, the research study's model can facilitate and improve critical discussions and understanding by acting as a source of existing knowledge of agriculture innovation adoption trends. This can further improve on areas that the research study might not have explored while facilitating the design and testing of different policies regarding population growth.

Additionally, the developed model can adapt to serve the purpose of investigating the adoption and diffusion dynamics of other agriculture innovations by government and development institutions. To enable this, it is proposed that the current model and insights of this research study should be demonstrated to prospective users, such as government policy designers, development organization as well as private sector investors who are keen to expand innovation investments in the agriculture sector.

A key component of such a demonstration would be a thorough analysis of the different needs and expectations of the different users for whom the model can an answer question. The model's current functionality and authenticity would then be assessed against these conditions and a product development proposal can be devised.

-End-

Appendix

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Model Equations

Top-Level Model:

Agricultural_Land(t) = Agricultural_Land (t - dt) + (Deforestation_for_Agriculture - Agriculture_Land_Degradation) * dt {NON-NEGATIVE}

INIT Agricultural_Land = INITIAL_AGRICULTURE_LAND

UNITS: ha

INFLOWS:

Deforestation_for_Agriculture = MIN (Desired_Change_in_Agriculture_Land, Forest_Land/Agriculture_Land_Conversion_Time) {UNIFLOW}

UNITS: ha/years

OUTFLOWS:

Agriculture_Land_Degradation = Agricultural_Land*Agriculture_Land_Degredation_Rate {UNIFLOW}

UNITS: ha/years

CIS_usage_Skills(t) = CIS_usage_Skills (t - dt) + (Change_in_Skills) * dt {NON-NEGATIVE}

INIT CIS_usage_Skills = INITIAL_CIS_USAGE_SKILLS

UNITS: dmnl

INFLOWS:

Change_in_Skills = (Indicated_Skills_from_CIS_Usage-CIS_usage_Skills)/Time_to_Acquire_CIS_Usage_Skills

UNITS: 1/year

DOCUMENT: changes in baseline skill levels, knowledge, farming practices and resource allocations within the household

CIS_USERS(t) = CIS_USERS (t - dt) + (Adoption_Rate - Dis_adoption_Rate) * dt

INIT CIS_USERS = 591013.381214025

UNITS: persons

DOCUMENT: Agriculture_Labour_Force*INITIAL_AGROMET_USERS

INFLOWS:

Adoption_Rate = (TEK_USERS_WITH_CIS_KNOWLEDGE*Total_CIS_Adoption_Potential)/EFFECTIVE_TIME_TO_ADOPT

UNITS: People/years

OUTFLOWS:

Dis_adoption_Rate = (Total_Dis_adoption_Potential*CIS_USERS)/TIME_TO_DISADOPT_CIS_Usage

UNITS: People/years

Degraded_Land(t) = Degraded_Land (t - dt) + (Agriculture_Land_Degradation - Forest_Regrowth) * dt {NON-NEGATIVE}

INIT Degraded_Land = 295000

UNITS: ha

INFLOWS:

Agriculture_Land_Degradation = Agricultural_Land*Agriculture_Land_Degredation_Rate {UNIFLOW}

UNITS: ha/years

OUTFLOWS:

Forest_Regrowth = Degraded_Land/Average_Forest_Regrowth_Time {UNIFLOW}

UNITS: ha/years

Farmers_Using_TEK_Strictly(t) = Farmers_Using_TEK_Strictly (t - dt) + (Forget_rate + Farmer_Population_Growth - Education_Rate) * dt

INIT Farmers_Using_TEK_Strictly = 3546080.28728415

UNITS: persons

DOCUMENT: INITIAL_TEK_USAGE*Agriculture_Labour_Force

INFLOWS:

Forget_rate = Forgetting_Proportion*TEK_USERS_WITH_CIS_KNOWLEDGE

UNITS: People/years

Farmer_Population_Growth = Population_Growth_Rate*Employment_to_Population_Ratio*Share_of_Labor_Force_in_Agriculture_Employment

UNITS: People/years

OUTFLOWS:

Education_Rate = (Farmers_Using_TEK_Strictly*Education_rate_through_contact+MIN(Farmers_Educated_by_Development_Organizations, Maximum_Education_Rate)+MIN(Farmers_Trained_through_Government_Services, Maximum_training_Rate))

UNITS: People/years

Forest_Land(t) = Forest_Land (t - dt) + (Forest_Regrowth - Deforestation_for_Agriculture) * dt {NON-NEGATIVE}

INIT Forest_Land = INITIAL_FOREST_LAND

UNITS: ha

INFLOWS:

Forest_Regrowth = Degraded_Land/Average_Forest_Regrowth_Time {UNIFLOW}

UNITS: ha/years

OUTFLOWS:

Deforestation_for_Agriculture = MIN (Desired_Change_in_Agriculture_Land, Forest_Land/Agriculture_Land_Conversion_Time) {UNIFLOW}

UNITS: ha/years

Population(t) = Population (t - dt) + (Population_Growth_Rate) * dt {NON-NEGATIVE}

INIT Population = INITIAL_POPULATION

UNITS: People

INFLOWS:

Population_Growth_Rate = Population*Fractional_Growth_Rate {UNIFLOW}

UNITS: People/years

Savings_that_matter_for_CIS(t) = Savings_that_matter_for_CIS (t - dt) + (Saving_rate_towards_accessing_CIS_Services - investment) * dt

INIT Savings_that_matter_for_CIS = 50

UNITS: USD/household

INFLOWS:

Saving_rate_towards_accessing_CIS_Services = TEK_Household_Savings*Effective_Savings_fraction

UNITS: USD/household/year

OUTFLOWS:

investment = IF CIS_Access_Affordability >=1 THEN Effective_Cost_of_Investment_towards_accessing_CIS/Investment_time ELSE 0 {UNIFLOW}

UNITS: USD/household/year

TEK_USERS_WITH_CIS_KNOWLEDGE(t) = TEK_USERS_WITH_CIS_KNOWLEDGE(t - dt) + (Education_Rate + Dis_adoption_Rate - Adoption_Rate - Forget_rate) * dt

INIT TEK_USERS_WITH_CIS_KNOWLEDGE = 7683173.95578233

UNITS: persons

DOCUMENT: Agriculture_Labour_Force*INITIAL_TEK_USERS_WITH_AGROMET_USAGE_SKILLS

INFLOWS:

Education_Rate = (Farmers_Using_TEK_Strictly*Education_rate_through_contact+MIN(Farmers_Educated_by_Development_Organizations, Maximum_Education_Rate)+MIN(Farmers_Trained_through_Government_Services, Maximum_training_Rate))

UNITS: People/years

Dis_adoption_Rate = (Total_Dis_adoption_Potential*CIS_USERS)/TIME_TO_DISADOPT_CIS_Usage

UNITS: People/years

OUTFLOWS:

Adoption_Rate = (TEK_USERS_WITH_CIS_KNOWLEDGE*Total_CIS_Adoption_Potential)/EFFECTIVE_TIME_TO_ADOPT

UNITS: People/years

Forget_rate = Forgetting_Proportion*TEK_USERS_WITH_CIS_KNOWLEDGE

UNITS: People/years

Trust_in_CIS(t) = Trust_in_CIS (t - dt) + (Change_in_Trust_in_CIS) * dt {NON-NEGATIVE}

INIT Trust_in_CIS = Initial_Trust_in_CIS

UNITS: dmnl

INFLOWS:

Change_in_Trust_in_CIS = (Indicated_Trust_in_CIS-Trust_in_CIS)/TRUST_ADJUSTMENT_TIME

UNITS: dmnl/years

Trust_in_TEK(t) = Trust_in_TEK (t - dt) + (Change_in_Trust_in_TEK) * dt

INIT Trust_in_TEK = 1-Initial_Trust_in_CIS

UNITS: dmnl

INFLOWS:

Change_in_Trust_in_TEK = (Indicated_Trust_in_TEK-Trust_in_TEK)/TRUST_ADJUSTMENT_TIME

UNITS: dmnl/years

Adoption_Potential_from_Trust_in_CIS = Trust_in_CIS

UNITS: dmnl

Agriculture_Labour_Force = Share_of_Labor_Force_in_Agriculture_Employment*Labour_Force

UNITS: People

Agriculture_Land_Conversion_Time = 12

UNITS: Years

Agriculture_Land_Data = GRAPH(TIME)

(2001.00, 12612000.0), (2002.00, 12812000.0), (2003.00, 13112000.0), (2004.00, 13262000.0), (2005.00, 13262000.0), (2006.00, 13462750.0), (2007.00, 13663500.0), (2008.00, 13914250.0), (2009.00, 14115000.0), (2010.00, 14265000.0), (2011.00, 14415000.0), (2012.00, 14465000.0), (2013.00, 14415000.0), (2014.00, 14415000.0), (2015.00, 14415000.0), (2016.00, 14415000.0), (2017.00, NaN), (2018.00, NaN)

UNITS: ha

DOCUMENT: WORLD BANK STAT

Agriculture_Land_Degredation_Rate = 0.0040005961695566

UNITS: dmnl/year

Average_Forest_Regrowth_Time = 50

UNITS: Years

Average_Household_Food_Requirements = Average_Household_Size*Per_Capita_Food_Requirements

UNITS: Tons/household/Years

Average_Household_Size = 8

UNITS: persons/household

Average_Yield = ((CIS_Adopter_Share*Yield_Potential_of_CIS_Users) +((1-CIS_Adopter_Share) *Yield_Potential_TEK))

UNITS: Tons/ha/year

CIS_Access_Affordability = MIN (1, (Savings_that_matter_for_CIS/Effective_Cost_of_Investment_towards_accessing_CIS))

UNITS: 1

CIS_Adopter_Share = CIS_USERS/Total_Knowledge_Coverage_of_CIS

UNITS: dmnl

CIS_users_yields = Yield_Potential_of_CIS_Users*EFFECT_OF_CIS_SKILLS_on_Users_Yields

UNITS: Tons/ha/year

Contact_Rate_with_Adopters = Farmers_Using_TEK_Strictly/(Farmers_Using_TEK_Strictly+CIS_USERS) *Farmer_to_farmer_Contact_Rate

UNITS: dmnl/year

Cost_of_Investment_towards_accessing_CIS = 120

UNITS: USD/household

Cultivated_Land_by_CIS_Users = Agricultural_Land*CIS_Adopter_Share

UNITS: ha

Cultivated_Land_under_TEK = Agricultural_Land*(1-CIS_Adopter_Share)

UNITS: ha

Demand_Supply_Ratio = Desired_Food_Requirements/Total_harvest

UNITS: 1

Desired_Change_in_Agriculture_Land = MAX (0, (Total_Desired_Agriculture_Land-Agricultural_Land)/Agriculture_Land_Conversion_Time)

UNITS: Hectares/Years

Desired_Food_Requirements = Population*Per_Capita_Food_Requirements

UNITS: Tons/Years

Desired_Subsistance_Household_Food_Requirements = Farmer_Households*Average_Household_Food_Requirements

UNITS: Tons/Years

"Dis-adoption_Potential_Due_to_Trust_in_TEK" = Trust_in_TEK

UNITS: dmnl

Education_rate_through_contact = Contact_Rate_with_Adopters*Proportion_of_Contacts_resulting_into_Education

UNITS: dmnl/year

EFFECT_OF_ADOPTION_ON_FARMER_SKILLS = GRAPH(CIS_Adopter_Share)

(0.000, 0.2000), (0.100, 0.2300), (0.200, 0.2900), (0.300, 0.4000), (0.400, 0.5900), (0.500, 0.7600), (0.600, 0.8800), (0.700, 0.9500), (0.800, 0.9700), (0.900, 0.9800), (1.000, 1.0000)

UNITS: dmnl

EFFECT_OF_ADOPTION_ON_TRUST = GRAPH(CIS_Adopter_Share)

(0.000, 0.000), (0.100, 0.065), (0.200, 0.256), (0.300, 0.467), (0.400, 0.665), (0.500, 0.780), (0.600, 0.885), (0.700, 0.969), (0.800, 0.991), (0.900, 0.991), (1.000, 1.000)

UNITS: dmnl

EFFECT_OF_CIS_SKILLS_on_Users_Yields = GRAPH(CIS_usage_Skills)

(0.000, 0.6000), (0.250, 0.7140), (0.500, 0.8360), (0.750, 0.9500), (1.000, 1.0000)

UNITS: dmnl

"EFFECT_OF_NON-_ADOPTION_ON_TRUST" = GRAPH(Share_of_CIS_Non_adopters)

(0.000, 0.000), (0.100, 0.0179862099621), (0.200, 0.0474258731776), (0.300, 0.119202922022), (0.400, 0.26894142137), (0.500, 0.500), (0.600, 0.73105857863), (0.700, 0.880797077978), (0.800, 0.952574126822), (0.900, 0.982013790038), (1.000, 1.000)

UNITS: dmnl

EFFECT_OF_RELATIVE_YIELD_ON_ADOPTION = GRAPH(Relative_Yield)

(0.000, 0.000), (0.500, 0.000), (1.000, 0.050), (1.500, 0.600), (2.000, 1.000)

UNITS: dmnl

EFFECT_OF_RELATIVE_YIELD_ON_DIS_ADOPTION = GRAPH(Relative_Yield)

(0.000, 1.000), (0.500, 0.700), (1.000, 0.050), (1.500, 0.000), (2.000, 0.000)

UNITS: dmnl

Effective_Cost_of_Investment_towards_accessing_CIS = Cost_of_Investment_towards_accessing_CIS-Subsidy_Amount

UNITS: USD/household

Effective_Savings_fraction = savings_fraction_for_met

UNITS: dmnl

EFFECTIVE_TIME_TO_ADOPT = IF TIME > Insurance_policy_start_time THEN Policy_time_to_adopt ELSE TIME_TO_ADOPT

UNITS: Years

EFFECTIVE_TRUST_ADJUSTMENT_TIME = IF TIME > Trust_policy_start_time THEN Policy_Trust_Adjustment_Time ELSE Trust_Adjustment_Times

UNITS: Years

Employment_to_Population_Ratio = GRAPH(TIME)

(2001.00, 0.68277), (2002.00, 0.68126), (2003.00, 0.6793), (2004.00, 0.67925), (2005.00, 0.68636), (2006.00, 0.69252), (2007.00, 0.69126), (2008.00, 0.68981), (2009.00, 0.68782), (2010.00, 0.68348), (2011.00, 0.68519), (2012.00, 0.68628), (2013.00, 0.69706), (2014.00, 0.69608), (2015.00, 0.69493), (2016.00, 0.6936), (2017.00, 0.6923), (2018.00, 0.69055)

UNITS: dmnl

DOCUMENT: https://knoema.com/atlas/Uganda/Employment-to-population-ratio

Farmer_Households = Agriculture_Labour_Force/Average_Household_Size

UNITS: household

Farmer_to_farmer_Contact_Rate = 0.5

UNITS: dmnl/year

Farmers_Educated_by_Development_Organizations = 0.3

UNITS: persons/year

Farmers_Trained_through_Government_Services = 0.4

UNITS: persons/year

FARMERS_using_CIS = (CIS_USERS/Total_Farmers) *100

UNITS: 1

Food_price = REFERENCE_FOOD_PRICE*Demand_Supply_Ratio^SENSITIVITY_OF_FOOD_PRICE_TO_DEMAND_SUPPLY_RATIO

UNITS: USD/ton

Food_Remained_after_Consumption = Total_harvest-House_Hold_Consumption

UNITS: Tons/Years

Food_sold_by_CIS_Users = Total_Harvest_of_CIS_Users*Fraction_of_Food_for_Sale

UNITS: Tons/Years

Food_Sold_TEK = Fraction_of_Food_for_Sale*Total_Harvest_TEK

UNITS: Tons/Years

Forest_Data = GRAPH(TIME)

(2001.00, 3781000.0), (2002.00, 3693000.0), (2003.00, 3605000.0), (2004.00, 3517000.0), (2005.00, 3429000.0), (2006.00, 3293800.0), (2007.00, 3158600.0), (2008.00, 3023400.0), (2009.00, 2888200.0), (2010.00, 2753000.0), (2011.00, 2612700.0), (2012.00, 2482600.0), (2013.00, 2343400.0), (2014.00, 2212200.0), (2015.00, 2077000.0), (2016.00, 1941800.0), (2017.00, NaN), (2018.00, NaN)

UNITS: ha

DOCUMENT: WORLD BANK STAT

Forgetting_Proportion = 0.1

UNITS: dmnl/years

Fraction_of_Food_for_Sale = Food_Remained_after_Consumption/Total_harvest

UNITS: 1

Fractional_Growth_Rate = 0.0338

UNITS: dmnl/year

Government_Services_Training_Time = 0.5

UNITS: Years

Harvest_Data = GRAPH(TIME)

(2001.00, 15039500.0), (2002.00, 14304346.9281), (2003.00, 13296100.0), (2004.00, 13180625.8824), (2005.00, 13038084.2471), (2006.00, 12960447.3), (2007.00, 13077510.9941), (2008.00, 13599052.8889), (2009.00, 14128895.7647), (2010.00, 14468058.8235), (2011.00, 14560831.0458), (2012.00, 14502580.3922), (2013.00, 14503900.5882), (2014.00, 14664145.0719), (2015.00, 14758579.5882), (2016.00, 13271350.7059), (2017.00, 13577951.4314), (2018.00, NaN)

UNITS: Tons/Year

DOCUMENT: FAO STAT

Uganda Bureau of Statistics (UBOS)] (2015) Statistical abstract. UBOS, Kampala, Uganda

House_Hold_Consumption = MIN (Desired_Subsistance_Household_Food_Requirements, Total_harvest)

UNITS: Tons/Years

Indicated_Skills_from_CIS_Usage = EFFECT_OF_ADOPTION_ON_FARMER_SKILLS

UNITS: dmnl

Indicated_Trust_in_CIS = EFFECT_OF_ADOPTION_ON_TRUST

UNITS: dmnl

Indicated_Trust_in_TEK = "EFFECT_OF_NON-_ADOPTION_ON_TRUST"

UNITS: dmnl

INITIAL_AGRICULTURE_LAND = 12612000

UNITS: ha

INITIAL_CIS_USAGE_SKILLS = 0.221

UNITS: dmnl

INITIAL_CIS_USERS = 0.05

UNITS: 1

INITIAL_FOREST_LAND = 3781000

UNITS: ha

INITIAL_POPULATION = 24850000

UNITS: People

INITIAL_TEK_USAGE = 0.3

UNITS: 1

INITIAL_TEK_USERS_WITH_CIS_SKILLS = 0.65

UNITS: 1

Initial_Trust_in_CIS = 0.046

UNITS: dmnl

Insurance_policy_start_time = 2021

UNITS: year

Investment_time = 1

UNITS: year

Labour_Force = Population*Employment_to_Population_Ratio

UNITS: People

Maximum_Education_Rate = Farmers_Using_TEK_Strictly/Time_to_learn_about_CIS

UNITS: People/years

Maximum_training_Rate = Farmers_Using_TEK_Strictly/Government_Services_Training_Time

UNITS: persons/year

Per_Capita_Food_Requirements = 0.5

UNITS: Tons/person/year

Per_Farm_Production_Cost_TEK_users = 20

UNITS: USD/household/year

Per_Farm_Revenue_TEK = Total_Farm_Revenue_TEK/TEK_households

UNITS: USD/household/year

Per_Small_Holder_Household_Expenses = GRAPH(TIME)

(2001.00, 30.00), (2002.00, 32.4682588406), (2003.00, 35.0860647), (2004.00, 37.8624783421), (2005.00, 40.8071095051), (2006.00, 43.9301501624), (2007.00, 47.2424097996), (2008.00, 50.7553528277), (2009.00, 54.4811382645), (2010.00, 58.432661819), (2011.00, 62.6236005261), (2012.00, 67.0684600859), (2013.00, 71.7826250706), (2014.00, 76.7824121739), (2015.00, 82.0851266863), (2016.00, 87.7091223924), (2017.00, 93.6738650969), (2018.00, 100.00)

UNITS: USD/household/year

policy_start_time = 2021

UNITS: year

Policy_time_to_adopt = 3

UNITS: Years

Policy_Trust_Adjustment_Time = 1

UNITS: Years

Population_Data = GRAPH(TIME)

(2001.00, 24388968.0), (2002.00, 25167257.0), (2003.00, 25980552.0), (2004.00, 26821297.0), (2005.00, 27684585.0), (2006.00, 28571475.0), (2007.00, 29486338.0), (2008.00, 30431736.0), (2009.00, 31411096.0), (2010.00, 32428167.0), (2011.00, 33476919.0), (2012.00, 34559168.0), (2013.00, 35695246.0), (2014.00, 36912148.0), (2015.00, 38225453.0), (2016.00, 39647506.0), (2017.00, 41162465.0), (2018.00, 42723139.0), (2019.00, NaN), (2020.00, NaN)

UNITS: People

DOCUMENT: WORLD BANK STAT

Proportion_of_Contacts_resulting_into_Education = 0.5

UNITS: dmnl

REFERENCE_FOOD_PRICE = 50

UNITS: USD/ton

Relative_Yield = CIS_users_yields/Yield_Potential_TEK

UNITS: dmnl

savings_fraction_for_met = 0.1

UNITS: dmnl

SENSITIVITY_OF_FOOD_PRICE_TO_DEMAND_SUPPLY_RATIO = 0.806720737081345

UNITS: dmnl

Share_of_CIS_Non_adopters = 1-CIS_Adopter_Share

UNITS: dmnl

Share_of_Labor_Force_in_Agriculture_Employment = GRAPH(TIME)

(2001.00, 0.696669), (2002.00, 0.69083), (2003.00, 0.687), (2004.00, 0.68498), (2005.00, 0.68353), (2006.00, 0.67892), (2007.00, 0.6757), (2008.00, 0.67253), (2009.00, 0.6706), (2010.00, 0.66816), (2011.00, 0.66437), (2012.00, 0.66136), (2013.00, 0.71917), (2014.00, 0.72585), (2015.00, 0.72633), (2016.00, 0.72839), (2017.00, 0.73052), (2018.00, 0.72875)

UNITS: dmnl

Subsidy_Amount = Subsidy_fraction*Cost_of_Investment_towards_accessing_CIS

UNITS: USD/household

Subsidy_fraction = STEP (Subsidy_fraction_policy, policy_start_time)

UNITS: dmnl

Subsidy_fraction_policy = 0

UNITS: dmnl

TEK_Household_Savings = MAX (0, Per_Farm_Revenue_TEK-(Per_Farm_Production_Cost_TEK_users+Per_Small_Holder_Household_Expenses))

UNITS: USD/household/year

TEK_households = Farmer_Households*((Farmers_Using_TEK_Strictly+TEK_USERS_WITH_CIS_KNOWLEDGE)/Total_Farmers)

UNITS: household

Time_to_Acquire_CIS_Usage_Skills = 3

UNITS: Years

TIME_TO_ADOPT = 3.5

UNITS: Years

TIME_TO_DISADOPT_CIS_Usage = 15

UNITS: Years

Time_to_learn_about_CIS = 0.5

UNITS: Years

Total_CIS_Adoption_Potential = EFFECT_OF_RELATIVE_YIELD_ON_ADOPTION*Adoption_Potential_from_Trust_in_CIS*CIS_Access_Affordability

UNITS: dmnl

Total_Desired_Agriculture_Land = Desired_Food_Requirements/Average_Yield

UNITS: ha

Total_Dis_adoption_Potential = "Dis-adoption_Potential_Due_to_Trust_in_TEK"*EFFECT_OF_RELATIVE_YIELD_ON_DIS_ADOPTION

UNITS: dmnl

Total_Farm_Revenue_TEK = Food_price*Food_Sold_TEK

UNITS: USD/year

Total_Farmers = Farmers_Using_TEK_Strictly + TEK_USERS_WITH_CIS_KNOWLEDGE+CIS_USERS

UNITS: People

Total_harvest = Total_Harvest_of_CIS_Users+Total_Harvest_TEK

UNITS: Tons/Years

Total_Harvest_of_CIS_Users = Yield_Potential_of_CIS_Users*Cultivated_Land_by_CIS_Users

UNITS: Tons/Years

Total_harvest TEK = Yield_Potential_TEK*Cultivated_Land_under_TEK

UNITS: Tons/Years

Total_Knowledge_Coverage_of_CIS = CIS_USERS+TEK_USERS_WITH_CIS_KNOWLEDGE

UNITS: People

TRUST_ADJUSTMENT_TIME = EFFECTIVE_TRUST_ADJUSTMENT_TIME

UNITS: Years

Trust_Adjustment_Times = 1

UNITS: Years

Trust_policy_start_time = 2021

UNITS: year

Yield_Potential_of_CIS_Users = 1.9

UNITS: Tons/ha/year

Yield_Potential_TEK = 0.95

UNITS: Tons/ha/year

{The model has 128 (128) variables (array expansion in parens).

In root model and 0 additional modules with 9 sectors.

Stocks: 11 (11) Flows: 14 (14) Converters: 103 (103)

Constants: 39 (39) Equations: 78 (78) Graphicals: 13 (13)

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