Exploring The Application of ICTs and Big Data Analytics on Climate Data in Climate-Smart Agriculture To Increase Productivity for Small-Scale Farmers: The Case of Ghana

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List of Abbreviations

ABDA………………………...Agricultural Big Data Analytics

AIS…………………………………………………………Agricultural Innovation Systems

ATPs……………………………………………………......Agriculture Technology Providers

BDA………………………………………………………………….,,,,,,,,Big Data Analytics

CCAFS……………………………………...Climate Change, Agriculture and Food Security

CDT……………………………………………………………Catalog Data Technologist

CGIAR……………………………Consultative Group on International Agricultural Research

CIS…………………………………………………………..Climate Information Services

CS……………………………………………………………………….....Climate Services

CSA……………………………………………………………Climate-Smart Agriculture

ESA………………………………………………………………European Space Agency

FAO……………………………………………………...Food and Agricultural Organization

GPS……………………………………………………………..Global Positioning System

ICRISAT……………………..International Crops Research Institute for the Semi-Arid Tropics

ICTs……………………………………….....,Information and Communication Technologies

IRI……………………………………International Research Institute for Climate and Society

IST……………………………………………………………..Innovation System Theory

NASA……………………………………....National Aeronautics and Space Administration

NEPAD…………………………………………...New Partnership for Africa's Development

NGOs……………………………………………………...Non-Governmental Organizations

NIS………………………………………………………...National Innovation Systems

NMS……………………………………………………..National Meteorological Stations

OECD……………………………..Organisation for Economic Co-operation and Development

PICSA………………………………Participatory Integrated Climate Services for Agriculture

R & D……………………………………………………….....Research and Development

SDGs……………………………………………………...Sustainable Development Goals

UN……………………………………………………………………………..United Nations

WMO……………………………………………………World Meteorological Organization

Executive Summary

As the world's food systems continue to undergo sectoral and digital transformations, new farming practices and intelligent technologies are periodically introduced in agriculture. Access to well-informed and real-time climate information promotes agricultural production. This study aims to explore how the application of ICTs and big data analytics in climate-smart agriculture can play a role in helping smallholder farmers maximize their productivity using sustainability means. It considers Ghana as a case of reference for conducting the investigation. Pivotal to any agricultural development and implementation program is to understand the past and present conditions of the targeted farming population, environment, and digital tools to reap the benefit for all crucial stakeholders. This thesis, therefore, asks: *under what conditions can the application of ICTs and big data analytics on climate data increase agricultural productivity for small-scale farmers?* To answer this research question, the study employs a systematic review and in-depth qualitative expert interviews. The systematic review was conducted over six months. Purposive and snowball sampling techniques were used to select experts for the interviews. It employs the innovation system theory and then draws on national innovation systems and the agricultural innovation system framework to develop the theoretical background as a guide for the study. Based on the methodological approach used, evidence shows that there are a few critical weaknesses in the provision and delivery of climate information to farmers; however, these weaknesses continue to reinforce each other in specific ways. They also impede the progress in meeting the climate service needs of smallholder farmers to scale their productivity. Results further demonstrate the need to have effective communication and face-to-face interaction with smallholder farmers during and after planting seasons. Furthermore, key challenges such as gaps in historical climate data, data accessibility and quality, political influence, inequalities, and technological hype are pointed out as factors that could heavily hinder using ICTs and BDA on climate data. Smallholder farmers can increase their productivity when: the gains from using ICTs and BDA adequately channelled back to them, accurate climate and weather information is communicated to smallholder farmers, smallholder farmers are trained and upskilled, the needed technologies are appropriately used, policymakers and governments are aware of differential effects and, ICT drivers and barriers are identified.

Keywords: smallholder farmers, ICTs, climate, productivity, climate-smart agriculture, big data analytics, Ghana, weather, small-scale farmers

1. Introduction

The fourth industrial revolution, commonly known as industry 4.0, has led to the adoption and use of various disruptive technologies in many sectors (FAO, 2010a). Agriculture, being one of the most critical sectors for the sustained growth of most countries, can also significantly benefit from them (Hallegatte & Rozenberg, 2017; Collier & Dercon, 2014). In particular, developing countries may use these digital tools efficiently using novel methods to increase agricultural productivity for small-scale farmers (FAO, 2013).

The rise in agricultural productivity in the past has primarily been defined by the large hectares of land that have been more intensively cultivated (Boto et al., 2012). Cultivating more land to increase agricultural productivity is attributed to conventional practices where agriculture used to be handled as an intuitive space with knowledge and wisdom of farming practices passed down from one generation to another (FAO, 2010b). However, it is now evident that such agricultural practices are not tailored to handle today's complex food, income, and climate problems. Cultivating more land for production is not a feasible farming practice. It has often resulted in many environmental degradations, such as elevated greenhouse gas emissions and deforestation (Antwi-Agyei et al., 2021). Relying on old farming wisdom passed down from generation to generation has even exacerbated the threat of climate change, food insecurity, and low income from agricultural production (Kusangaya et al., 2014).

The changing climate and rapid growth in the global population (FAO, 2019) are a testament to the fact that innovative agricultural practices are indeed needed to counter these challenges to maximize agricultural productivity using science, technology, and policy-based methods (Hansen et al., 2011) to meet the sustainable development goals (SDGs) of zero hunger, no poverty, and climate action (Kusangaya et al., 2014). In the last couple of years, we have seen how data and digital technologies are changing the traditional ways international development programs are developed and implemented (Friedrich et al., 2009). The proliferation of various cutting-edge technologies results in the massive availability of digitally generated data, often used by many sectors to make intelligent predictions and decisions. These same technologies are currently playing a significant role in maximizing agricultural output for (small-scale) farmers (Friedrich et al., 2009). The affordability of most common digital devices (FAO, 2019; FAO, 2014) makes it possible for various agriculture and food systems to generate, gather, and analyze climate data. Climate data gathered using ICTs may be harnessed within agriculture to maximize the global agricultural productivity to counter the increasing food demand by a vast growing global population. Climate is one of the significant determinants of crop and animal production for farmers in Sub-Saharan Africa. For example, in Africa, agriculture depends heavily on rainfall (OECD/FAO, 2016; FAO, 2014), making rural livelihoods and food security highly vulnerable to variability in climatic conditions (Friedrich, Shaxon & Kassam, 2009). As such, it is imperative to base major farming decisions on past, present, and future climate data (Kelly & Adger, 1999; FAO, 2019).

The World Bank Group (2017) defines ICT as any device, tool or application that permits the exchange or collection of data through either transmission or interaction. It is a broader term that includes any digital devices or services such as radio, mobile phones, satellite imagery, electronic money transfers, televisions, etc. Whereas CSA is defined as a sustainable farming approach to mitigate climate change, improve farmers' livelihoods through increased income and productivity, and reduce the level of greenhouse gas emissions (Huyer & Nyasimi, 2017). However, BDA encompases techniques and technologies used to amass large datasets and apply intelligent data analytics practices to extract value from data and build prediction models that can be trained to improve over time (Popa, 2011).

This study aims to analyze the use of Information Communication Technologies (ICTs), Big Data Analytics (BDA), and Climate-Smart Agriculture (CSA) using Ghana as a case of interest. First, it explores the agricultural sector of Ghana in general. It then picks two essential cases as a point of reference for the analysis. To complement the findings from the cases in Ghana, a compelling case in Senegal that uses ICTs to help smallholder farmers is also analysed. The research question under study is to understand the conditions under which the application of ICTs and big data analytics on climate data can help increase agricultural productivity for small-scale farmers. A systematic review and in-depth qualitative interviews address the said research question. It also employs ideas from innovation system theory, agricultural innovation system, and national innovation system to identify key actors and their roles in implementing and developing policies to enable smallholder farmers to derive maximum benefits from new farming techniques using innovative tools. This study hopes that its findings and recommendations could benefit agricultural stakeholders in sub-Saharan African and beyond to better tailor farming practices and new digital tools to the needs of small-scale farmers.

The structural organization of the remainder of this study is as follows. The background and problem statement, aims and objectives of the study, research rationale and the research question are presented as sub sections under the introduction. Section two discusses the findings of the literature review. Section three presents the theoretical background and discusses key theoretical elements and frameworks. Section four extensively describes the methodological undertaking, and section five presents the main findings. The final few sections, sections six and seven introduce the discussion and conclusion. The bibliography and appendix follow these last two sections.

1.1 Background and Problem Statement

The Population Division report of the United Nations estimates the world population to be growing at around 81 million per annum. The median estimate projects the world population to be around 9.7 billion by 2050 (United Nations, 2019). This growth means that agriculture is faced with multi-faceted challenges such as feeding a massive number of people, providing farmers with livelihoods, and combating environmental hazards such as climate change. CSA using ICTs and BDA are necessary tools to face and solve these challenges. However, despite the development of various CSA practices and their positive outcomes, understanding how these technologies, together with BDA, are currently being used in CSA to benefit small-scale farmers remains unclear. It is, therefore, essential to understanding the synergy between ICTs and BDA in CSA for the sustainable maximization of agricultural productivity for small-scale farmers. Most researchers and agricultural policymakers believe that agricultural practices using the potentials of ICTs and BDA may not only maximize agricultural productivity but could also help mitigate climate change hazards. Through the lens of BDA and ICTs, CSA can focus on the generation, gathering, and analysis of climate data to generate helpful climate insights such as trends and patterns and implementing climate forecasting models for better farming decisions.

Furthermore, agriculture is the primary source of income for a large part of the populations of most agriculture-based countries, such as Sub-Saharan African countries (Zougmore et al., 2016; Nangombe et al., 2018). To this end, agriculture is not the primary income provider for populations in Sub-Saharan Africa but also for the larger global population that is increasing rapidly. In the next few years, the world will have to confront the challenge of feeding a massively growing population (FAO, 2019; FAO, 2011a) while maintaining sustainability and providing economic growth, poverty reduction (FAO, 2010). Food and Agricultural Organisation (FAO) estimate shows that close to 78 percent of the world's impoverished population still largely depends on agriculture for employment and sustenance (FAO, 2019). These estimates show that the global food systems need to adopt agricultural practices that are scalable, sustainable, and environmentally friendly to nutritiously feed over 9 billion people (World Bank, 2011; World Bank, 2007). According to FAO, the increasing demand for food means that the world needs to produce an estimated 50% more food to feed over 9 billion people by the year 2050 (FAO, 2019; FAO & NEPAD, 2002).

The ultimate need to produce enough food to feed the ever-increasing global population means that all stakeholders need to intensify their efforts in finding new sustainable ways to meet our food demand (FAO & NEPAD, 2002). Furthermore, efforts and resources need to be utilized in agriculture and food systems to counter the challenge of food insecurity (FAO, 2011b). However, suppose our agriculture and food sectors are not ballooned to adapt and utilize the powers of the technologies around us. In that case, poverty will increase, climate change will persist, and malnutrition will significantly increase in most parts of the world (Serdeczny et al., 2017). As mentioned earlier, it is no secret that the current agricultural (and food) systems are not meeting these goals as they should. Thus, innovative transformations are needed at an unprecedented rate to counter the threat of global hunger by providing food security, driving economic growth in rural and urban areas, and mitigating the problems posed by climate change (Nwajiuba et al., 2015). At the same time, the technological revolution of the past decades is driving technological innovations across a wide array of sectors. However, agriculture and food systems primarily responsible for feeding and providing income for many countries have been relatively slow to benefit from these innovative technologies. Therefore, agriculture and food systems need to efficiently and cautiously speed up their adoption and use of these technologies to sustainably maximize global food production and increase income for small-scale farmers while being aware of the limitations and gender disparities in developing countries. This study will contribute to enhancing the understanding of the potentials of ICTs and BDA in agriculture and how those potentials can be harnessed for broad access and usability by small-scale farmers in developing countries.

1.2 Aims and Objectives of the Study

The main aims and objectives of this study are to:

1. Provide baseline data on the status of knowledge on agriculture, CSA, ICTs and BDA
2. Give and explain the conditions under which smallholder farmers can benefit from the use of ICTs and BDA on climate data
3. Establish an understanding of the roles of ICTs and BDA techniques in the generation and analysis of climate data
4. Describe sample case studies where such innovative practices are used and what the outcomes were
5. Address the concept of data-driven agriculture
6. Establish the relationship between CSA and climate information services (CIS)
7. Explain the interplay between the key actors in the CSA ecosystem
8. Provide critical recommendations on how ICTs, CSA, and BDA can be mainstreamed in the agricultural development programs of Sub-Saharan Africa
9. Identify, document, and collect data on the successful CSA practices and actions for scaling up agricultural productivity.

1.3 Relevance and Significance of study

The results of this study can help agricultural stakeholders play a central role in meeting the global food demand by using ICTs (Collier & Dercon, 2014) to generate and analyze climate data using BDA techniques. The adoption of CSA by agricultural stakeholders and ICTs and BDA may help meet the sustainable goals of zero hunger, no poverty, and climate action (FAO, 2019). So, it is essential to understand the necessary conditions for applying ICTs and BDA on historical climate data to benefit smallholder farmers. While some research has been done on the roles of ICTs in agriculture, very few have focused on how they can be effectively harnessed to benefit smallholder farmers. Moreso, very little research has been conducted to identify the relevant key players, the primary beneficiaries, and data flow in this type of novel farming.

The increasing awareness of climate action and the use of ICTs in various sectors suggest that farmers and essential stakeholders in agriculture are aware of the need to integrate ICTs in agriculture to combat climate change, enable increased economic progress, and counter food insufficiency (Sultan et al., 2020). However, it is currently unclear to what extent farmers directly engage with agriculture and climate policies in this field of study. It is, therefore, crucial to gain a broader picture of using ICTs to generate, gather, and store climate data. Gaining a picture of the extent to which climate data can be generated using ICTs and the subsequent analysis using data analytics techniques may help mitigate climate change and increase agricultural and economic output for small-scale farmers. Using ICTs and BDA approaches in CSA would add to sustainable intensification by strengthening the resilience of agriculture and food systems to climate variability and climate change with the potential to reduce greenhouse gas emissions (Prasad et al., 2016). CSA alone encourages sustainable intensification practices and policies across countries and regions (Gubbels, 2013). These implementation policies and practices may be significantly valuable for developing countries, most of whose populations' livelihoods come from subsistence agriculture.

1.4. Study Rationale

Sometime between 2001 and 2002, The Gambia was severely hit with a prolonged drought that lasted for many months and hindered farming activities in significant ways. Later, it was learned that the drought-affected The Gambian farmers and had severely affected the agricultural systems of most Sub-Saharan Africa. The selection of types of crops and determining a suitable time for planting and other agronomic practices in most parts of the world remain a challenge (Niang et al., 2014; Zougmore et al., 2018) due to a lack of reliable and informative weather or climate information to small-scale farmers (Adenle et al., 2017; Jones et al., 2015; Vaughan & Dessai, 2014). The Sub-Saharan region produces an estimated 30% of the food requirements of Africa (Taylor et al., 2017), yet, conditions such as drought, severe extreme weather events, economic degradation, famines, and frequent food insufficiency are commonly seen features in the region.

Small-scale farmers in Africa mostly rely on long years of farming experience to make a heuristic estimation of climatic conditions. Unfortunately, these estimations are primarily inaccurate and have often led to poor farming decisions (Coulibaly et al., 2015), resulting in low agricultural produce, meagre income, and severe environmental degradation such as deforestation, soil erosion, overgrazing, and over-cultivation of arable lands - all these contribute to climate change thereby further affecting food production and income generation through agriculture (Nwajiuba et al., 2015).

In most cases, small-scale farmers' access to available climate information for agricultural decision-making is scanty (Nwajiuba et al., 2015). Moreover, there is often a misalignment between the reported climate information needs and accurate or exact information provided by the National Meteorological Agencies in developing countries The National Meteorological Agencies across West African states (Nkiaka et al., 2019). Factors such as poor observational records, frail computational facilities, lack of technical know-how, and other issues such as insufficient investment in data-driven agriculture are all part of the reasons for poor farming decisions made by farmers in most developing countries (Kusangaya et al., 2014). On the other hand, suppose farmers rely on reliable climate and weather information from local authorities or extension services. In that case, such poor farming decisions could be averted (Brasseur and Gallardo, 2016). With reliable weather and climate information (Nkiaka et al., 2019), farmers may both know and understand when and where to plant their crops and how they can apply suitable crop and animal husbandry practices on their farms. Data-driven agricultural practices in CSA may help small-scale farmers access reliable climate information because they can know the best time to plant and harvest their farm produce and ready them for sale in the market. Therefore, it is highly imperative in this technological age for agricultural stakeholders to prioritize climate information to build resilience in food systems and inform national-level planning and development (Antwi-Agye et al., 2021).

The emergence of new cutting-edge technologies in the last couple of decades and the speed at which these technologies continue to be improved and tailored to meet human needs in many sectors make them widely applicable in agriculture - most especially CSA. Today's technologies generate large amounts of structured and unstructured data for businesses, governments, and other corporations (small, medium, and large). Therefore, agricultural stakeholders, most especially those involved in the development of agricultural leverage programs for sustainable agriculture (Sultan et al., 2020), should come up with best practices that incorporate these technologies into agriculture to maximize agricultural production, promote food and financial security for small scale farmers while at the same time mitigating climate change (Brasseur and Gallardo, 2016). In recent years, the agricultural sectors of most developed countries continue to develop and implement CSA practices to combat climate change and increase farm productivity

(Brasseur & Gallardo, 2016). Agricultural development programs in these countries aim at developing CSA approaches using the power of digital tools. However, for most developing countries globally, Sub-Saharan Africa in particular, the affordability and availability of some of these technologies is sometimes limited for small-scale farmers (Gubbels, 2013). Moreover, even if they are available, they may not have the right skills to harness them efficiently.

1.5 Research Question

Using innovative technologies in agriculture to benefit smallholder farmers is often viewed from different angles. While many consider these innovations in agriculture as necessary and critical to combat many global challenges, others see them as mere technological hypes that fail to materialise in the long run. Many new technologies have been introduced in the agricultural sectors of developing countries. The governments of these countries are working with their ministries of agriculture and other partners to encourage adopting and using these farming approaches, especially in rural regions; however, there are many challenges and barriers. Practices such as CSA and climate information services work in parallel to mitigate climate change hazards and help smallholder farmers develop climate resilience and increase productivity. Historical climate data to make weather forecasts and climatic predictions is the main foundation based on which these two farming approaches operate. The generation, analysis and communication of helpful weather information to smallholder farmers is aided by ICTs and BDA. Although smallholder farmers may have access to timely and reliable climate information, smallholder farmers can benefit from new farming approaches and tools depending on several conditions. Thus, this study poses the question: ***under what conditions can the application of ICTs and big data analytics on climate data increase agricultural productivity for small-scale farmers?***

2. Review of Literature

Climate-Smart Agriculture (CSA) is a topical issue widely discussed and is being viewed as an approach to mitigate climate change, improve farmers' livelihoods through increased income and productivity, and reduce greenhouse gas emissions. Policymakers and key stakeholders in agriculture are actively seeking ways to adopt this new farming approach to counter the numerous challenges facing the world's food systems. These challenges range from climate variability, food insecurity, environmental degradation, among others. To complement the approach of CSA in battling the challenges currently facing our food systems and other sectors, research shows the need to introduce novel approaches that will further advance the goals of CSA to benefit smallholder farmers in developing countries. The exponential growth of data and the number of ICTs in recent years has led to the adoption of techniques in agriculture that harness the power and potential of these tools to maximize productivity for small-scale farmers and mitigate significant agricultural challenges. These techniques range from using BDA in agriculture, using smart ICTs for climate data collection and monitoring, and the agglomeration of these two techniques in acting on the data and transmitting the obtained insights to farmers for better decision making. This literature review explores various research angles within CSA and the role ICTs and BDA play in increasing agricultural productivity for farmers, particularly smallholder farmers. While conducting the literature review, special attention is paid to relevant publications on CSA and the use and roles of ICTs and BDA in agriculture. The review provides an overview of current knowledge within agriculture, thereby identifying research strengths and gaps. This review summarises sources and analyzes, synthesizes, and critically evaluates them to provide a clear overview or picture of the state of knowledge on CSA, ICTs, and BDA and their role in maximizing agricultural productivity for smallholder farmers. Due to the recurring central themes of this research, this literature review is organized into themes that address different topical areas. Sections that follow below discuss the state of knowledge on how BDA and ICTs are used in CSA, data-driven agricultural approach, ICTs and BDA for maximizing productivity for farmers. An overview is also given on CSA and the recorded impacts of ICTs and BDA on small-scale farmers..

2.1 State of Knowledge on BDA and ICTs Use in Climate-Smart Agriculture

Before delving deeper into the research that has thus far been done on the use of BDA and ICTs in CSA, it is imperative first to establish a strong understanding of the progressive development of the agricultural industry in recent years. This understanding will pave the way for the broader comprehension of CSA and the role BDA and ICTs play. Many significant changes in the agricultural industry show the direction it is heading and how BDA and ICTs will play a central role in benefiting small-holder farmers in developing countries. Ryan (2020) categorized the agricultural industry into four main distinctive markets. These markers are the farm equipment, chemicals, fertilizers, and seeds. From the 1990s to the mid-2000s, there had been a significant shift in the agricultural sector, reducing these four market categories to three. For example, based on the research by Pham & Stack (2018), seeds and chemical fertilizers are now a single category due to aggressive mergers and acquisitions.

One business area that has developed rapidly in recent years is data retrieval, processing, analytics, and predictive and prescriptive advisory services (Janzen & Ristino 2018). The development of these businesses provides new opportunities for small-holder farmers to venture into new products and business models to maximize their agricultural productivity (Kshetri, 2014). Data has become a very well used and valuable commodity in the agricultural industry (Ryan, 2020) which is evidenced by the numerous volumes of agribusinesses purchasing technology start-ups, investing in their data systems and architectures, and the desired need to push towards a complete digitalization of farms (Bunge, 2017). Agricultural data comes in many formats. For example, ICTs are used in most agricultural practices today to gather climate and weather information from various sources. The climate data generated from ICTs are processed and acted upon by BDA to generate insights that are sometimes communicated to farmers through Climate Information Services (CIS) (Wolfert et al., 2017). This data reliance phenomenon in agriculture leads to what is known as 'data-driven agriculture' (Vellante, 2015). A data-driven approach leads more and more investment companies to digitize agriculture through mergers and acquisitions of agribusinesses due to the value of data and its role in agriculture. The abundance of acquisitions and mergers in the agricultural sector is the driving force behind the booming business of data science. Such acquisitions and mergers can be seen through a record of the history of the business models of most agricultural and non-agricultural companies over the years.

The recently observed pattern in the investment in data acquisition and analytics shows companies' willingness to shift or abandon their traditional farming methods; it has further demonstrated their increasing interest in using and implementing ICTs and data analytics technologies in agriculture. The agricultural industry is a big industry that generates over five (5) trillion dollars annually and accounts for ten percent (10%) of the world's domestic product (Murray, 2007). This figure is possibly even higher today. Thus, agriculture conglomerates divert their attention from traditional business models as seed and chemical providers to a more data analytics approach. The agricultural market is a vast profit-generating machine. It is estimated that the big giants that dominate this market will take centre stage and lead the race to adopt big data analytics techniques and ICTs to drive the world food industry (Ryan, 2020). However, the question that remains is ‘how do all these technologies and novel approaches benefit small-holder farmers in the short and long term?’ The patterns show that big agricultural tech giants will most likely focus on improving their profit and achieving a competitive edge in the market (Ryan, 2020). Thus, new strategies and agricultural policies need to be made to secure the position of small-holder farmers and seek to improve their productivity and livelihoods in the face of power dynamics and threats of acquisitions from larger agricultural firms. The agriculture data market is becoming big business and is projected to grow significantly over the next couple of years (Ristino, 2018). Monsanto Company has estimated the impact data analytics will have on the global crop production level. Bunge (2017) put this estimate to 20 billion dollars per year. Major agribusinesses with global and national dominance, which would have sold physical products and other valuable intellectual resources to farmers, are not seen branching into the big data analytics market because of profitability and an increased competitive edge and agricultural market dominance. Based on these recent shifts in the agricultural sector, it is clear that the future of agriculture now lies in technological development and reliance. However, technologies may have consequences for certain agricultural players through political interventions, power relations, and technological triumphalism.

One of the most recent agricultural technological improvements is in the field of data retrieval and BDA. The field of data retrieval and BDA in agriculture allows for gathering agricultural data such as weather and climate information, which are assessed to detect patterns and trends. The discovered patterns and trends are used to make strategic farming decisions for farmers. For example, ICTs such as smartphones, satellites, and meteorological stations are used to gather climate information which is then acted upon using BDA to generate actionable and valuable insights for farmers through CIS to prescribe alternatives concerning the time of planting, harvesting, watering, weeding, and the general upkeep or care of the farm. There is an increasing level of data-driven agricultural adoption for farmers through ICTs and BDA. Over the past decade, the agricultural sector has seen a significant shift towards a data-centric agricultural prescription practice for farmers (Ryan, 2020).

When there is access to data and analytic capabilities on the farm, it allows for a much better prescriptive and predictive analysis. In the past decade, there has been an emergence of the Agriculture Technology Provider (ATP). ATP is a business component of successful corporations that have a heavy role in a merger transaction with other highly successful corporations and purchasing small companies such as small agribusinesses. Monsanto, Bayer, John Deere, BASF, and Pioneer are examples of successful corporations that can sometimes be considered ATPs due to their role among themselves and other small companies. However, when talking about ATPs, the only thing that is being sold is knowledge in the place of traditional seeds, fertilizers, machinery, or chemicals (Bennet, 2015). The shift from selling and acquiring physical agricultural products to a more knowledge-based transaction implies that agribusinesses are not completely ignoring their traditional businesses but are instead incorporating and embedding them within this new knowledge-based service.

The transformation from dealing with physical products to knowledge-based services with ATPs involves making a contractual agreement with farmers. It requires farmers to agree to specific terms and conditions from the ATP and, in turn, get some benefits. The farmer has to agree to allow ATP to collect specific data on the farm or install a data retrieval tool on the farm. The type of data collected on the farm includes soil moisture and temperature, farming activities, rainfall level, crop growth patterns, climate conditions, soil nutrient levels, and land irrigation (Kamilaris et al., 2017). Once the agreement between the farmer and an ATP is reached, the ATP has the freedom to embark on installing a range of data collection or data retrieving tools on the farm and the surrounding areas to gather more valuable and quality quantitative data. ICTs are the primary data retrieving tools (Kamilaris et al., 2017). When more persistent and far-reaching quality data is collected on the farm, the ATP then uses BDA on the data to analyze and generate insights. The ATP does the data analyses on the farm, and the analyzed data is benchmarked with datasets obtained from other farms. The acquired and analyzed data and the analyses on datasets obtained from other farms are simultaneously analyzed in conjunction with regional analysis, meteorological data, satellite imagery, and local data acquired by the ATP (Bennet, 2015). Once the analyses are completed, the ATP then calculates, plots, and determines the best possible methods to obtain sustainable yield for the farmer (Ryan, 2020). Farmers benefit from the ATP's data insights through the ATP obtained from their farm data through the prescriptive farming recommendations. Such prescriptive farming recommendations through the use of ICTs and BDA may not have been possible in the past (Bennet, 2015).

2.2 Understanding The Pillars of Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture (CSA), as defined by the Food and Agricultural Organization (FAO) of the UN, is a form of agricultural practice that sustainably increases crop and animal productivity, enhances the resilience of livelihoods and ecosystems, reduces or entirely removes greenhouse gases, and plays a role in enhancing national food security programs and development goals (Huyer & Nyasimi, 2017). An alternative definition of CSA by Thornton, Whitbread et al. (2018) defined CSA as an approach that seeks to reorient agricultural implementation and development programs under the banner of climate change and climate variability. Hansen et al. (2019) defined CSA as an approach that may help transform food systems and reorient agricultural development programs under the current, past and future realities of climate change and variability.

Based on these definitions and the numerous other definitions highlighted in the literature, it is evident that CSA represents an opportunity for countries in African to scale up to more robust and cleaner agricultural production technologies that increase both the climate resilience of farming sectors and enhance food security (Lipper et al., 2015).
Lipper et al. (2015) provided a concise understanding of the goals of CSA by summarising the three pillars on which it is based. The goal of CSA is to achieve sustainable development for global food security, improved livelihoods, and climate change adaptation and mitigation visa three pillars. These pillars are given by Lipper et al. (2015) as follows:

- To sustainably increase agricultural production in both crops, livestock, and fish, to contribute to achieving food and nutritional balance and security, generate higher incomes without posing damages to the environment or natural ecosystem;
- To adapt to climate change and climate variability (FAO, 2018) with a primary focus on reducing exposure to risks and improving farmers' capacity to adapt and develop in the face of

many forms of unforeseen natural unrest or hazards such as shocks and long-term stresses, maintaining a balanced ecosystem that gives farmers better environmental services;

- To reduce and remove greenhouse gas emissions in areas or situations where possible, such as the reduction in emissions for each kilogram of food, fibre, and fuel produced globally, conserving the environment by avoiding deforestation through extreme agricultural practices, and managing the soil and trees so that they become carbon sinks, thus absorbing Carbon dioxide from the atmosphere.

Mwalupaso et al. (2019) posit that if farmers in Africa substitute their current conventional farming practices deemed unclean with CSA practices, they will play a significant role in helping to transform agricultural systems sustainably. They will also heavily help in both the mitigation and adaptation pillars of CSA (Richards et al., 2016). The critical nature of CSA in countering today's many agricultural challenges should, therefore, motivate policymakers, donors, researchers as well as other stakeholders to focus their efforts in making the pillars of CSA a reality for small-scale farmers through the introduction of new science, technology, and policy-based practices (Amarnath, Simons, Alahacoon, et al., 2018). Practices such as using BDA techniques and introducing more intelligent ICTs in agriculture may help advance agricultural systems by scaling up productivity for small-scale farmers. Lipper et al. (2015) promulgated for the prioritization of research aimed at development activities as a crucial need to utilize the limited resources available to farmers and food systems as effectively as possible. To meet this prioritization technique, frameworks can help assess and compare different CSA research investments (Amarnath et al., 2018); however, no such frameworks existed until one was developed by Thornton et al. (2018).

According to Richards et al. (2016), many areas make prioritizing CSA research a challenge, including the pillars on which it is based (productivity, adaptation, and mitigation), the uncertainty around climate impacts, and the scale and contemporary dependencies that may hinder the adoption, cost, and mitigation of CSA. Because of the lack of well-defined frameworks in CSA research, a study conducted by Thornton et al. (2018) proposed a new framework that prioritizes agricultural research investments that span multiple scales. They reviewed different approaches that helped them set priorities among many research projects within agriculture. The study is based on many priority-setting case studies that address short to medium-term goals of CSA practices at local scales (Thornton et al., 2018). The framework they propose suggests that a mixture of actions spanning spatial and temporal scales is needed in today's agricultural systems to adapt to climate change and variability, address immediate problems, and create conditions that enable farmers to endure these circumstantial climate changes.

CSA includes multi-dimensional approaches that use proven practical techniques such as crop rotation, intercropping, conservation agriculture, mulching, improved grazing, efficient water management, integrated crop and livestock management, agroforestry, and conservation agriculture (Roudier et al., 2014). Furthermore, it also introduces novel, innovative practices such as heavy weather forecasting dependence, early-warning systems, and climate-risk insurance schemes. The definition of CSA by various scholars and proponents is centred around the notion of it being reflective of the ambition of further merging agricultural enhancement programs through maximizing productivity and climate responsiveness (Mwalupaso et al., 2019). It is significantly evident in the literature that there is a link between climate variability and food insecurity. Andrieu et al. (2019) explained that climate variability is a significant contributor to food insecurity and an impediment to efforts to improve rural livelihoods across countries in sub-Saharan Africa and that climate change is further intensifying this problem. Climate services are seen as increasingly crucial in CSA for adaptation by smallholder farmers in the agricultural sector (Muema et al., 2018) by providing fundamental knowledge comprising of the local climate and weather information that may help to inform the decisions of these farmers as well as the institutional decision making (Thornton et al., 2018). These farming decisions based on CIS help support a range of resilience-building intervention programs that provide an enabling environment for CSA adoption (Dinku, Asefa, Hilemariam, Grimes, & Connor, 2011). While there is established evidence of the role of national meteorological services in providing climate information within a national context, Dinku et al. (2011) reasoned that much of the research and effort that are seeking the delivery and use of climate services in the agricultural sector of African countries had remained mainly at a pilot scale. As a result, the body of experience offers significant insight into the challenges farmers face in accessing, using, and benefiting from climate information (Hansen et al., 2019). Climate services are decision support tools developed to transform climate information into meaningful information communicated to farmers through extension and advisory services (Dinku et al., 2011). Climate service is responsible for providing a piece of well-tailored and usable climate information to policymakers and vulnerable farming communities based on the currently available weather information, for example, a forecast of flooding, heavy rainfall, or expected drought.

Despite the recent progress and advances in the use of CSA as a novel agricultural approach to help meet the UN's SDGs of zero hunger, no poverty, and climate action, it has been heavily contested by many as a hype that may fail to materialize effectively as it is envisioned, particularly concerning social equity (Thornton et al., 2018). There is a growing concern that CSA may lead to the transfer of the burden of responsibility for climate change mitigation to people who are not competent enough to handle it (Karlsson et al., 2017). People such as marginalized producers and resource managers will be confronted with additional challenges beyond their handling and understanding capacity, resulting in a situation where the risks of climate change will increase. The remaining two pillars will suffer as a result of climate variability. Karlsson et al. (2017) argued that CSA gives very little attention to entrenched power relations that may block the emergence of new and more equitable and expandable agricultural systems. While support for CSA has mainly come from many African countries (Roudier et al., 2014), the mention of agricultural adaptation and the mention of CSA in their national policy documents remains very limited. Although, in the wake of the Paris Agreement, many countries in the world, particularly in Africa, have gravitated their attention and agricultural implementation efforts to use CSA as a viable solution that can meet most of their agricultural needs (Richards et al., 2016). Chandra et al. (2017) and Purdon & Thornton (2017) viewed the inclusion of equity considerations in CSA as an approach and remains a work in progress while at the same time arguing that research is now emerging on the politics and governance of transformation and adaptation practices that are needed in food systems in the future.

2.3 Link Between ICTs, BDA and Agricultural Productivity

Climate change has played a role in keeping smallholder farmers at the bottom of the agricultural value chain (Ray et al., 2015).) Thus, farmers can no longer rely on conventional practices such as timework coping strategies when all of the benchmarks used in making farming decisions are becoming less reliable. Severe and unexpected weather is further shrinking the scarce resources and yields of small-scale farmers and promoting migration from rural areas to urban areas (World Economic Forum, 2017). Research has shown that many weather-related events in developing countries often leave the governments of developing countries to cope with major agricultural failures in crops and animals and the failure to cope with displaced victims at the right time (World Bank Group, 2017). The governments of these countries lack the resources and investments from the private sector to provide climate and weather risk management instruments to help advance their agricultural systems (Karki, Burton, & Mackey, 2020). Herrero et al. (2017) explained that smallholder farmers contributing to a significant portion of the global food production need the information to increase their farm yield just the same way information is provided to industrial-scale farmers. When the two types of farmers are compared, it becomes clear that small-scale farmers are in a more disadvantaged position than industrial-scale farmers. The FAO (2019) described this disadvantage stating that wealthy industrial farmers can use the internet, mobile phones, weather forecasts, and other intelligent ICT tools as well as technologies to glean information on prices, services, storage, or processing at the expense of small-scale farmers, and this only further exacerbates the productivity and income gap between the two groups of farmers. Smallholder farmers depend primarily on the oral transmission of information such as word of mouth and their previous farming experiences or advice from local leadership (World Bank Group, 2017). With ICTs, farmers can subscribe to allowing climate and farm information to be collected from their phones through installed sensors and applications in return for certain benefits such as reducing the price of seeds, fertilizers, machinery, and being part of insurance policies. In this context, the disadvantage of smallholder farmers may further increase because financial and insurance services are primarily out of reach and, other times, poorly understood by small-scale farmers. Even though many issues should be considered when using ICTs and BDA techniques in CSA, Jimenez et al. (2019) showed that these challenges and other issues could be addressed by effectively using them in farming practices. Figure B depicts how ICT enabled services can support poor rural livelihoods.

Figure A. ICT enabled services for supporting rural livelihoods

In recent years, the world has witnessed the development and growth of many innovative ICTs tools currently being used in many areas of agriculture (FAO, 2019). For CSA in particular, the roles of ICTs cannot be overemphasized. With the wide availability of mobile phones to most farmers, farmers are now able to effectively communicate with extension services and with each other to share or receive useful farming information. CSA in itself involves the use of intelligent ICT tools such as the Internet of Things (IoT), sensors, satellites, drones, and farm machinery to meet three main pillars; increasing productivity, income, and livelihoods; mitigating climate change; and reducing or eliminating greenhouse gas emissions (Bennet, 2015). The main focused area of CSA is increasing climate food production while mitigating climate variability. ICTs such as satellites, mobile phones, sensors, meteorological stations, and drones are being used to collect climate and weather information in real-time, stored and later analyzed using BDA and other analytical technologies to generate insights (Ribarics, 2016). Once the insights are generated, ICTs such as mobile phones, television, local radios, and other digital communication devices disseminate weather information to farmers (Bunge, 2017). Using ICTs to generate climate and weather data and acting upon these data to both derive and communicate insights is helping farmers to make better farming decisions, such as knowing about the right time of planting and harvesting, when to apply fertilizers, which crops to plant, and so on (Bennet, 2015). A study conducted by Karki et al. (2020) found that farming decisions based on actionable climate data not only help to maximize productivity for farmers but also help farmers adapt to more climate resilience farming methods and thus mitigate climate change (Jimenez, 2018).

Jimenez et al. (2019) argued that understanding and addressing the global agricultural development programs are crucial to smallholder livelihoods in which ICTs play a significant role. This is because the continued increase in globalization and integration of food systems have heightened efficacy and competition in the agricultural sector. Such intensive competition and efficiency have brought opportunities within the agricultural sector to include many smallholder farmers in supply chains. However, in the same line of reasoning, one can argue that agriculture faces a range of challenges that are particularly common in developing countries where many farmers are exposed to the risk of climate change and continued deficiencies of vital infrastructure in rural areas (Mehrabi et al., 2018).

The World Bank (2013) developed a report on 'Data Collection and Monitoring' using ICTs in agriculture, which shows the extent to which ICTs are being used in agriculture over the past years to help farmers scale farm productivity. The study was primarily developed to assist practitioners in assessing and selecting ICT applications suitable for rural agricultural projects. This report put a significant emphasis on mobile phone technology for data collection. Karki et al. (2020) also argue for mobile phones for climate data collection in CSA. They state that mobile phone usage has become so pervasive due to the wide availability and affordable cost. Although mobile penetration has risen globally, there are still gender disparities that hinder its accessibility and usage by women in most developing countries, mainly sub-Saharan African (World Bank Group, 2019). Using mobile phones for data collection is helping to solve most of the data collection challenges that ATPs and climate data collection and monitoring centres face in highly decentralized projects. Selecting technologies for use in climate data is a challenge due to the many options and specific needs of projects. The 2013 report by The World Bank was developed to help development practitioners stay up-to-date with the changing technology to help them identify the best platforms and means for assessing and choosing technologies to support data collection, storage, and analysis to determine and measure outcomes. Based on the report, there is the need for guidance to be provided to ATPs and farmers in selecting and applying technologies for (climate) data collection within the lens of agricultural projects.

According to Jiménez et al. (2019), governments and development practitioners can use ICTs to enhance their collection and monitor and evaluate their rural development projects.
Tracking the various stages of progress in sustainable agriculture is challenging (World Bank, 2013) due to long distances, sparse populations. Interventions ranging from policies to crop and livestock practices and the role and voices of farmers are indeed critical for the continued success of agricultural projects and programs (World Economic Forum, 2017). Landini's (2016) analysis shows that recent approaches that centre around the issue of climate impacts and land use within the context of CSA and landscape approach further add to the already complex issues of climate change in the face of the increasing global population and thus, require efficient data collection techniques and proper and efficient analysis methods in CSA. Furthermore, an increased level of unpredictability in terms of climate and weather patterns has affected the productivity of agriculture of small-scale farmers and increased the risks associated with the lives of these farming communities and those who depend on them (Jimenez et al., 2019). In this lens, the urgency and need to generate reliable climate data through the use of ICTs and analyze them effectively for better farming decisions using BDA techniques have increased sustainably; given the global concern around food production due to an increasing population and the effects of climate change (Ribarics, 2016). In addition, sustainable agricultural solutions such as CSA are becoming more interconnected and knowledge-focused, requiring climate data on and off the farm for decision making.

Parallel to increasing climate concerns is a trend that is quite promising. This promising trend is seen in the fast-moving, cost-effective and widely spread ICTS – especially mobile phones. The 2017 report of the world bank shows that the affordability of mobile phones has made them viable tools for data collection. With ICTs, near real-time feedback from the field is now possible because these technologies facilitate agricultural stakeholders such as development partners to oversee operations across dispersed locations, generate datasets faster and efficiently, analyze and evaluate results more often. Howland et al. (2015) described the need for using ICTs in collecting climate data in real-time. Real-time data collection and reporting allow for a tighter and more precise feedback loop to practitioners who actively implement agricultural programs to benefit farmers. For example, providing rural farmers with an up-to-date weather information report helps them prepare for their farming activities on time and seek help and advice from extension workers (World Bank, 2013). According to an executive report by the World Bank

Group (2017), the systematization of ICTs in climate data collection, monitoring, and evaluation also enables the accountability of different stakeholders. The report further suggests that it also supports evidence-based decision-making and paves the way for effectively allocating resources to maximize productivity and improve farmers' livelihoods. To complement practitioners' effort and growing interests in utilizing the powers of ICTs in agricultural sectors, the World Bank published important reports mainly on 'information technology (IT) in rural landscapes' in 2011. The reports within the IT report are 'ICT in Agriculture e-Sourcebook', 'Information and Communication for Development' report, 'transform Africa' report, and 'Forest Governance 2.0: A Primer on ICTs and Governance' report (World Bank, 2011, World Bank, 2012).

The ICT in Agriculture e-Sourcebook report primarily explains how digital technologies such as mobile devices, applications, software, among others, can be used within fourteen different subtopics in agriculture. The subtopics range from crop and animal productivity to risk management. The other report published in 2012 is the Information and Communication for Development which looks into the use of mobile devices across different sectors, including agriculture, while the e-Transform Africa paper dives into data and insights for the power of ICTs in transforming agricultural and non-agricultural sectors. Finally, the report titled 'Forest Governance 2.0: A Primer on ICTs and Governance' investigates the role of technologies in agriculture. These technologies range from radio and mobile devices to highly sophisticated technologies such as satellite imagery. The report explains how these tools are used to increase public participation and enhance economic progress. What all these reports highlight are the opportunities found within the ICT usage in CSA. However, the report did not explain how smallholder farmers can benefit from the powers of ICTs and how the gender differential effects, power and information asymmetry, and the already digital gaps can be addressed. Unless these gaps are filled, ICTs may become another technology hype that will fail to materialize in the long run to benefit all farmers equally.

Reflecting on the progress made since these reports were published, the World Bank report in 2013 argued for the improvements made on multiple facets. One significant area of improvement that was cited in the report is the mobile telephony infrastructure. This leapfrog impact of ICTs has increased access to quality and reliable climate and farm information, sharing knowledge quickly and efficiently. In addition, it has created opportunities to improve transparency and accountability in the field of CSA. The expansion of ICTs in agriculture has also made agricultural development programs and policymakers easier and extension services more accurate and timely (FAO, 2019). The 2013 report of the World Bank emphasizes that efficient and precise data collection within the agricultural sector are integral components that should not be left out.

2.4 The Role of Big Data Analytic in Climate-Smart Agriculture

The world is confronted with the enormous challenge of increasing agricultural production to meet the rising demand for food security of the twenty-first century. Increasing agricultural production is essential to feed a global population projected to reach 10 million by 2050 (United Nations, 2018). It is estimated that the world needs to produce 70% more food by 2050 to sustain this rapid growth while our overall ecological footprint is twice the level that it should be (FAO, 2009). Popa (2011) estimated that this growth could come from an additional 10% of new farmland. The remaining 90% can come from the existing land. These challenges are very daunting, and to counter them effectively, farmers need to increase their yield, make better farm management decisions, and avoid or minimize waste to ensure a sustainable and equitable ecological balance for the present and the future (Ryan, 2020). The majority of scholars claim that one possible solution to meet our agricultural needs is big data technologies to improve farming efficiency (Popa, 2011). Figure C below shows we can visualize the estimated gains from big data and business analytics across various sectors.

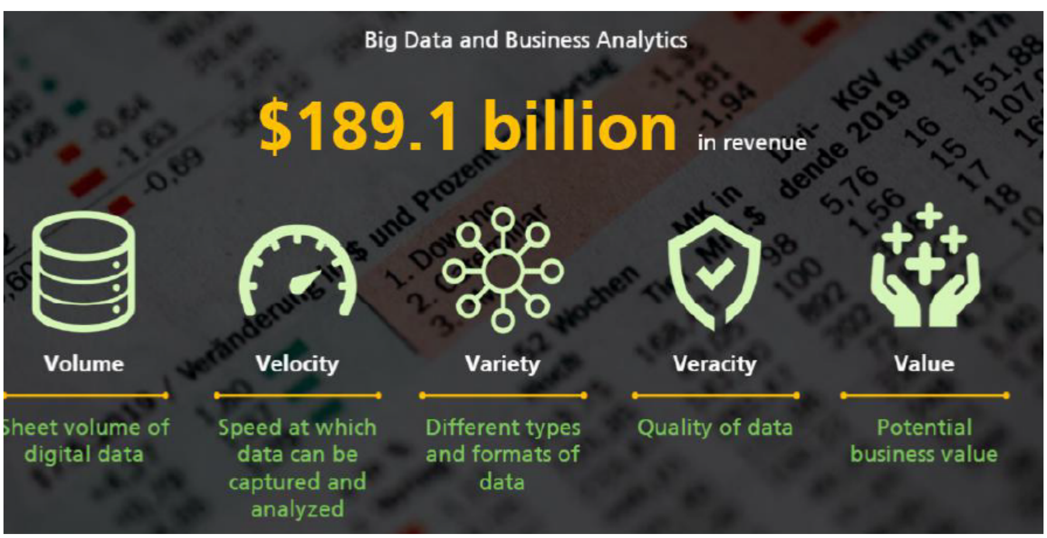


Figure C. Estimated revenue from Big Data and Business Analytics (World Bank Group 2017)

Big data Analytics (BDA) has been proposed by many agricultural policymakers and agricultural technology providers (ATPs) as a potential solution to counter or mitigate some of the challenges facing the world's food systems and environment (Delgad et al., 2019). To buttress the importance of using BDA in CSA, Ryan (2020) gave a new name to it, referred to as Agricultural Big data Analytics (ABDA). Ryan defines ABDA as a combination of Agricultural Big data, artificial intelligence, and machine learning technologies to determine decision-making on the farm and better farming practices (Ryan, 2020). The need to confront the global food challenge as a result of the rapidly increasing world population while at the same time confronting the challenge of climate change has even further exacerbated the current complex situations, and thus, puts massive pressure on agricultural systems to cater to the needs of small-scale farmers whose primary source of food and income is subsistence agriculture (Delgado et al., 2019). These enormous challenges have called for immediate solutions. Over the past years, BDA in CSA has been viewed to ensure better farming practices, decision-making, and a sustainable future for humankind. Countering the threats of climate change hazards, food security, improved livelihoods and income, and sustainability is a global battle that can be overcome through the concerted efforts of all agricultural and non-agricultural stakeholders employing information exchange through (active) collaboration (United Nations, 2018).

Through (active) participatory-collaborative information exchange among various agricultural stakeholders, valuable data can be gathered, analyzed, and acted upon to make better farming decisions. Climate and weather information are practical data elements that can be acted upon using big data technologies to generate valuable and timely weather and climate information for farmers for better farming decision-making, such as knowing the best time for planting and harvesting crops (Brasseur & Gallardo, 2016). Providing timely weather and climate information to farmers can reduce poor decision-making due to unexpected weather events. According to Pruski and Nearing (2002), when there is an increase in weather events, the potential for erosion in agricultural systems will increase. Erosion leads to infertile land and the reduction of arable land. Pruski and Nearing (2002) report that for every 1% increase in total rainfall, the erosion rate could increase by 1.7% due to climate change. Without conservation practices, humanity will probably not adapt to a changing climate (Delgado et al., 2019). Therefore, to maintain and increase the productivity and sustainability of agricultural systems, conservation practices will be essential (Spiegel et al., 2018). Climate variability is one of the significant determinants of food production in sub-Saharan Africa, most of whose population relies on rain-fed agriculture.

Without resorting to conservative practices in agriculture, the livelihoods of these poor small-scale farmers will be negatively hindered (United Nations, 2018). Extensive data analysis is proposed by Delgado et al. (2019) as one of the tools that will contribute to the development of sustainable (agricultural) systems. Wolfert, Ge, Verdouw, and Bogaardt (2017) suggested that the principal key to developing a better innovative farm in CSA is the application of big data.

Climate-Smart Farming which is other times referred to as CSA involves the use of ICTs in the 'cyber-physical farm management cycle' (Wolfert et al., 2017, p. 1) to meet the three main goals of CSA: increasing the food productivity and income, mitigating climate change, and possibly reducing or stopping greenhouse gas emission (FAO, 2019). The significant data phenomenon encompasses the use of ICTs in CSA. Big data is defined by Wolfert et al. (2017) as data of massive size and variety that can be captured, analyzed, and used for making decisions. In CSA, ICTs such as sensors, GPS, mobile phones, satellites, and robots gather climate data combined with local data from meteorological stations. The climate data continuously being gathered will grow in size to become massive and account for what is known as big data (Wolfert et al., 2014). While many scholars view big data as any massive data with a wide variety, some scholars have it that data does not necessarily need to be considered big data.

Bronson & Knezevic (2016) also saw the need to identify effective methods to maximize food production and sustainability for the global population. Bronson & Knezevic's (2016) review of current big data applications in the agri-food industry shows that several collection and analytics tools may have implications for different stakeholders in agriculture. Their review of existing literature concerns itself with data ownership rights and privacy issues in data collection for agricultural purposes. Based on their findings from the study of 'Big data in Food agriculture', they found that efforts are needed to understand the systematic tracing of the digital revolution in agriculture and exploring both the affordances and the limitations of data for agriculture. Such a goal will bring into the conversation the data collection techniques suitable for maximum production in the modern world and focus on the material consequence of big data in society. It is undeniable that every domain in the world is undergoing a digital transformation. Agriculture, being one of the most reliable food sources for the global population, is no exception to this. While describing big data in agriculture for better decision-making, Bronson & Knezevic (2015) gives an example of tractors fitted with sensors that stream data about soil and crop conditions while inviting farmers to subscribe to such services and pay for access to information that can help them make decisions and make sound judgments. Even small-scale farmers are now gathering information from within their communities and precision agricultural equipment types (Nanni et al., 2014).

2.5 Data-Driven Agriculture for Small-Scale Farmers using ICTs and BDA

Resorting to a more data-centric agricultural approach is essential to meet the myriad challenges confronting our food systems (FAO, 2019; Jiménez et al., 2019). As the effect of climate variability continues to negatively hinder food systems, mitigating the direct and indirect effect of this variation for small-scale farmers is an essential agricultural element for global food security (Ray et al., 2015). Food systems face the challenge of maximizing productivity using less land and resources to combat climate change and ensure an ecological balance. Cultivating more land is not a viable solution to meet the challenges we currently face (Ricciardi et al., 2018) because such farming practices contribute immensely to environmental degradation. According to Herrero et al. (2017), around one-quarter of the world's food is produced by small-scale farmers on farms under two hectares. Despite the immense contribution of small-scale farmers living in developing countries to agriculture and food systems, these farmers are faced with severe financial and infrastructural hardships that limit their access to new advanced digital agricultural tools (Mehrabi et al., 2018). It is evident that smallholder farmers in developing countries have no reliable access to information on climate and weather conditions (Jiménez et al., 2019); hence, they are often unable to analyze weather patterns and predict climatic trends based on past data and make data-based decisions for future farming activities (Landini, 2016).

Farmers' inaccessibility to weather and climate information is a context showing how many small-scale farmers obtain knowledge on which crops to grow and how to manage them. Jiménez et al. (2019) noted that most farmers obtain information from other farmers through word of mouth and extension services. For most farmers, direct farmer to farmer discussions and individual decision making suited to their needs rather than being told what to do (Herrero et al., 2017). Although, according to Steinke et al. (2017), when growers' organizations support farmers, they are often given two choices: take it or leave it all technological packages based on results from experiments being done and managed by researchers. Therefore, the information packages often transmitted by extension agents usually take the form of a top-down approach with little or no opportunities for farmers to express their voice and concerns on what should be done to ensure their survival and adaptation to specific conditions (Landini, 2016; Rosenheim & Gratton, 2017). To counter this information asymmetry, a study conducted by Jiménez et al. (2019) demonstrated in their study an opportunity to use modern ICTs and BDA technologies to provide smallholder farmers with data-driven agricultural advice and guidelines to manage their crops and livestock properly. The study shows how a data-driven approach in agriculture may minimize the year-to-year climate variation, improve productivity in terms of yield and income for small-scale farmers, and ensure food security. One other study conducted by the ministry of agriculture in Colombia shows how a data-driven agricultural program was developed (Jiménez et al., 2019). Based on this report, three main elements were used in developing the data-driven agricultural program are:

1. Information compiled from multiple data sources

2. Interpretation of this information

3. Presentation of the insights generated from the data to farmers through advisory services and extension agents

The results of their study demonstrated that machine learning techniques combined with expert advice explained how variation in weather, soil, and management practices affect the maize yield of small-scale farmers (Jiménez et al., 2019). The knowledge they obtained was further used to provide recommendations and guidelines on best management practices that should be adopted to yield high and more stable yields. According to (Jiménez et al., 2019), the principles applied in this study can be extended to rain-fed crops to mitigate the risk and failure of small-scale farmers. The study, however, falls short of clearly explaining how small-scale farmers can be effectively involved in the whole data-driven ecosystem to ensure they are not taken advantage of by industrial farmers. Figure D below shows how data can be used in agriculture to maximize productivity.

Figure D. ICTs, Data and Human interaction and exchange of information

Using a data-driven approach in agriculture complements traditional research efforts by integrating information from various sources using ICTs and including those from farmers themselves (Araya et al., 2010; Lacy, 2011). Approaches in CSA such as data-driven agriculture purely based on climate data means that the concerted effort of multiple institutions and agencies with diverse roles and expertise would have to come together and work closely to obtain climate data from farms over several years (Jiménez et al., 2019), analyzed the data to generate actionable insights that would then be communicated to farmers and other decision-makers. When farmers are provided with more accurate weather information, it helps them overcome certain risk factors by adopting the best practices during and after planting. Climate variation continues to be a challenge (Howland et al., 2015). Using ICTs and BDA in a data-driven model to obtain and analyze climate data will help maximize food production and contribute significantly to mitigating climate change hazards (Nakano et al., 2018). Jiménez (2018) suggested that the criteria for collecting any data are such that it should be sufficiently detailed to clearly distinguish the features of the crops, environments, and management of individual farming events. This type of characterization ensures an establishment between crop performance, the environment, and crop management. The figure below shows how ICTs and BDA can act on data in making informed and real-time decisions.

Figure E. Using ICTs and BDA for informed real-time decision making (FAO, 2019)

2.6 The Interplay Between Smart Agriculture and Big Data Analytics

Wolfert, Ge, Verdouw & Bogaardt (2017) defined smart farming as a development that stresses the use of ICTs in the farm management cycle. They expect that intelligent farming will be leveraged with the help of new technologies. It will introduce the use of more robots and artificial intelligence in farming. These technologies are encompassed by big data, a massive and proliferating volume of data with an expanded variety that can be captured, analyzed, and used in making intelligent farming decisions (Wolfert, Ge, Verdouw & Bogaardt, 2017). Wolfert, Ge, Verdouw & Bogaardt (2017) continued to argue that as intelligent machines and sensors continue to be used in farms by farmers, farm data will grow in quantity and scope, making farming processes increasingly data-driven and data-enabled (p. 1).

Micheni (2015), citing the United Nations Global Pulse (2013), defines big data as an umbrella term that pinpoints massive amounts of digital data continually produced by different people. He refers to it as "...the explosion in the quantity and diversity of high-frequency digital data, and the innovations which allow for its storage and analysis" (p. 44). Similarly, big data is described by (Vellante, 2015) as consisting of immense, distributed aggregations of loosely structured data with many characteristics. Some of these characteristics of big data were developed by Gartner (Laney, 2001), who typically defined it in terms of 3Vs (Volume, Variety, and Velocity). Two other vital Vs that later come to be discovered and added to the definition of big data are Value and Veracity (Micheni, 2015).

According to Rima (2015), big data emanated into the world due to new technological innovations and the increase in the affordability of digital devices worldwide. His arguments are supported by the fact that people's daily interactions with specialized tools result in much data being produced globally (Bellagio Big data Workshop Participants, 2014). Micheni (2015) strengthens this argument based on the wide availability of today's digital data from various sources by stating that digital data is being produced across the world at an unimaginable rate as people go about their daily lives in an ever-changing technological world. This data can be harnessed with the help of new computational techniques in big data to generate new insights from data, make predictions, and allow room for future analysis (Bellagio Big data Workshop Participants, 2014). Data in digital form is easily accessible with new innovative tools. These forms of data are higher in value and quality than traditional data forms (Micheni, 2015). Collecting enormous amounts of agriculture-related data using ICTs through crowdsourcing from the global population can result in significant data (Bronson & Knezevic, 2016). Bronson & Knezevic argued that big data differs from traditional information gathering in volume and the vast analytical potential using the modern computational tools embedded in contemporary digital technologies. A large proportion of big data proponents predict a high level of precision, information storage, processing, and analysis in new ways that were not previously possible due to technological limitations (Datafloq, 2015). With the vast availability of affordable ICTs such as the mobile phone, farmers (large scale farmers and small-scale farmers) have easy access to tools with which they can collaborate to share helpful information and with experts to improve on their farming practices, yield more income and farm produce, and most importantly ensure sustainability (Wolfert et al., 2017).

2.7 Impact of ICTs and BDA in CSA on Smallholder Farmers

The use of intelligent ICTs and BDA technologies in CSA is becoming spread amongst small-scale farmers. There is a direct link between the productivity of smallholder farmers and ICTs and BDA technologies in CSA. Research has shown that many farmers who use science-technology-based approaches in agriculture are gaining traction and improving their crop and livestock productivity, improving livelihoods, and mitigating climate change through clean farming methods (Branca et al., 2021). Although some smallholder farmers benefit from the gains in agricultural productivity through BDA and ICTs, many farmers are still without access to these tools, further widening the productivity gap between the farmers. Without better adaptation, access, and use of these tools by all marginalized smallholder farmers, income levels will decrease rapidly, and undernourishment will increase in Africa (Branca et al., 2021).

At the time of this writing, it is estimated that more than 250 million people are undernourished in Africa. This figure corresponds to about 19.1 per cent of the global world population. Current statistical estimates show that such a proportion will rise to 25.7 per cent by 2030. Any such increase will bring Africa off the track to achieve the SDG goals of Zero Hunger (United Nations, 2019b). According to FAO et al. (2020), many undernourished families are found in the sub-Saharan Africa subregion. Therefore, the subregion will need to increase crop production by about 260% by 2050 (United Nations, 2019a). In addition, a report by FAO et al. (2020) showed that climate variability and widespread, prolonged drought conditions have resulted in a drop in crop yields in several countries. As a result, small-scale farmers must increase their productivity to boost agricultural products' supply and improve food security and livelihoods (United Nations, 2019b).

Empirical evidence from past studies shows that climate change poses a significant risk to the growth of sub-Saharan Africa's agricultural and economic sectors. Branca et al. (2021) described farmers' sustainable resilience and mitigation capabilities in smallholder households as a critical political-economic goal that should be achieved to help enhance the productivity of small-scale farmers. A study conducted by Branca et al. (2021) assessed the on-farm economic benefits of CSA production and the cost-effectiveness analysis used as a criterion to make farm policies. The study was an interdisciplinary model which combines various economic and ecological elements at a farm-scale based on a unique dataset built through household surveys. The results from this study through household surveys show that farmers who switched from conventional farming practices to CSA practices have registered enhanced economic returns in semi-dry areas than in sub-humid tropics. However, the generated results also indicate a surge in up-front cost and how this hindered technology adoption (Branca et al., 2012).

Another study was done by Amarnath et al. (2018) in the Gash Delta of Eastern Ghana uses smart ICTs and Data Analytics technologies to forecast floods to smallholder farmers practising spate irrigation in the regions. Spate irrigation is known to substantially contribute to the improvement of rural livelihoods by providing better farm yields when compared to rainfed dryland agriculture. Nevertheless, this type of irrigation has dramatically affected the unpredictability of heavy flooding. Moreover, in recent years, the number of farmers who practice spate irrigation has drastically reduced due to unpredictable rainfall intensity and frequency. Based on the study by Amarnath et al. (2018), one viable solution that may help farmers manage such natural challenges is for them to have access to real-time weather-specific information using smart ICTs. Their research shows how remote sensing, flood forecasting models, communication forums, and Geographical Information Systems (GIS) can be integrated in real-time to alert smallholder farmers and relevant stakeholders such as government departments about impending floods (Amarnath et al., 2018). The results from this show demonstrate the increased potential of integrating intelligent technologies such as remote sensing, both open source and private data and simple agro-meteorological models for the monitoring of spate-irrigations systems. Data gathered using such innovative technological approaches can be analyzed using BDA to obtain actionable insights that can be used to forecast future floods and weather patterns to farmers through information sharing to advise farmers on how to apply such information to their farming and managerial decisions (Armanath et al., 2018).

3. Theoretical Background

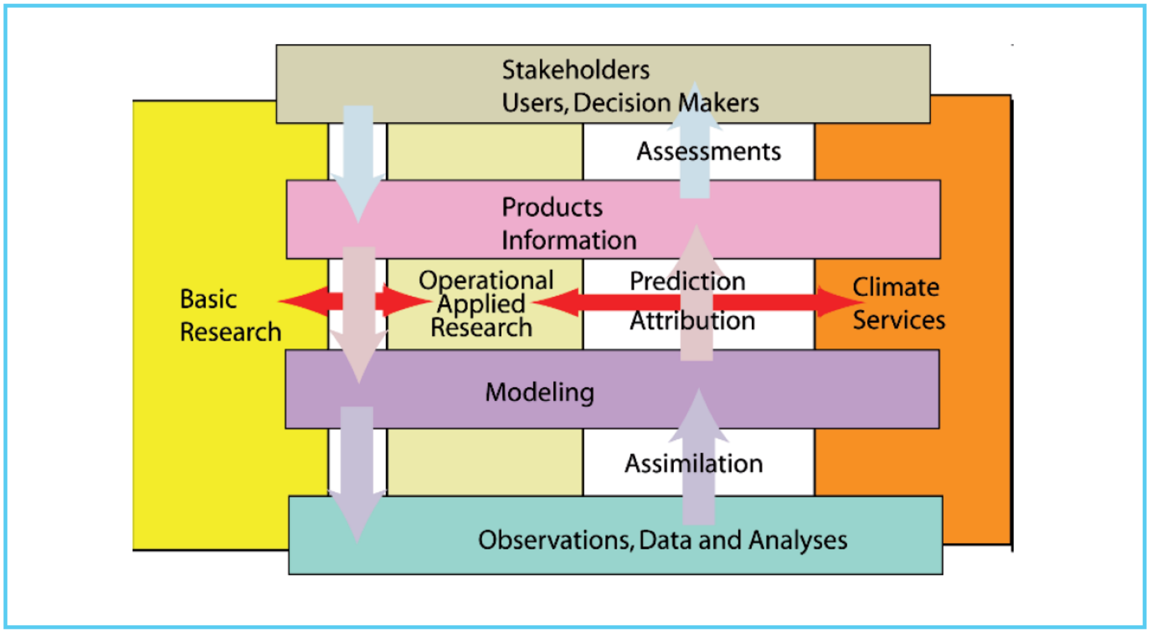
Climate change and variability continue to emerge as threats across the African continent and the world, hindering agricultural productivity for smallholder farmers. It has been observed that climate change is adversely impacting the agricultural productivity and livelihoods of small-scale farmers in developing countries. For example, Africa has a fast-growing population with an estimated annual growth rate of 2.4%. However, this growth will double by 2050 (FAO, 2011), and the continent has more than a quarter of its population undernourished. Therefore, its agricultural systems must undergo innovative transformations to simultaneously tackle poverty, food insecurity, climate change, and environmental degradation (Antwi-Agyei, Dougill, Doku-Marfo, & Abaidoo, 2021). Practices that use ICTs and BDA for climate data generation and analysis in CSA are being adopted in many countries. They are viewed as innovative approaches that can help smallholder farmers maximise their productivity, raising livelihoods while being climate-sensitive. The research question below seeks to investigate the use of ICTs and BDA on climate data in CSA and the (potential) impact on small-scale farmers' productivity: ***Under what conditions can the application of ICTs and big data analytics on climate data increase agricultural productivity for small-scale farmers?***

ICTs are knowledge sharing and delivery methods that can help to improve access to information such as weather information and raise awareness about CSA practices. At the same time, BDA is an advanced method for acting on large datasets and deriving insights (Westermann, Thornton & Forch, 2015). The amount of data generated from ICTs is enormous and increasing exponentially because of the wide-scale use of many cutting-edge technologies. As a result, the value of data to most organizations has seen a substantial increase to new heights due to the invaluable insights gained from data through the application of data analytics technologies for intelligent decision making. These same technologies can be used in agriculture. They may help counter the problems of climate change, food insecurity, and poverty. ICTs are being used by national, regional, and international organizations to generate and accumulate climate data for analytical purposes. With these technologies in agriculture, new climate patterns may be uncovered to make accurate climate and weather predictions for small-scale farmers to determine the best time for their farming activities. Having reliable climate and weather information may help small-scale farmers to resort to agricultural practices that increase their productivity in terms of income and improved livelihoods while at the same time mitigating climate change hazards.

Climate-Smart Agriculture (CSA) involves using any practice and technologies to sustainably increase agricultural productivity, support farmer's adaptation to climate change, and reduce the levels of greenhouse gas emissions (Antwi-Agyei, Dougill, Doku-Marfo, & Abaidoo, 2021). According to the FAO (2013), sustainable agriculture can be achieved through CSA. One of the prerequisites needed to achieve CSA objectives is climate information services (CIS). CIS is being used to enable vulnerable or marginalized communities to reduce risks primarily attributed to climate and allow different economy sections to make informed decisions. CSA addresses climate change while increasing productivity by the systematic integration of climate information into the development and planning programs of sustainable agricultural systems (FAO, 2013). The principal objective of this integration is to ascertain sustainable livelihoods in the face of climate change. Since CSA is knowledge sensitive, it requires access to information to enable actors/stakeholders to make well-informed decisions. CIS involves the generation, analysis and dissemination of climate information through ICTs and BDA tools. OECD (2015) identifies climate change as the major contributing factor to low productivity in agriculture; global warming and other extreme weather events add pressure on global food systems.

CIS covers the entire process of generating climate data, storing it, and processing it into specific products needed by various stakeholders. According to the World Meteorological Organization (WMO) (2011), climate services involve a wide range of measures and activities that engage in the generation and provision of information based on past, present, and future climate and its influence or impacts on natural and human systems. In addition, CIS complement CSA by making weather forecasts and climate predictions. Weather is defined by WMO (2011) as the state of the atmosphere at a given time and place using temperature, moisture, pressure and wind as variables. On the other hand, the climate refers to the average weather in terms of the variability and mean over a specific area and time. WMO (2011) also distinguishes between climate change and climate variability in the following ways. First, climate change is regarded as any change that persists for a more extended period.

In contrast, climate variability is any change in the measured statistics of climate elements over a short period. The diagram below illustrates a climate generation information system. It explains how climate data is generated using ICTs, analysed using BDA tools, and how the translated output is communicated to and used by the different actors.



Source: Sivakumar, 2015

Figure 1. Climate Data Generation System (Sivakumar, 2015)

3.1 Innovation System Theory and Agricultural Innovation Systems

The innovation system theory (IST) posits that innovation and technology development results from complex relationships among actors in the system (Hermans, Apeldoorn, Stuiver, & Kok, 2012). Actors within an innovation system include both human and non-human actors. For some scholars, the innovation ecosystem could be a subset of the innovation system. IST evolved and has been developed into an Innovation Systems Perspective, which presents a broad analytical framework that helps to examine technological change in agriculture as a complex process of interactions and actions among various actors (Kamara et al., 2019). These actors are often engaged in the generation, exchange, and use of knowledge, as well as the socio-economic institutions that condition their actions and interactions (Spielman & Birner, 2008). The IST encompasses both AIS and national innovation systems (NIS).

According to Klerkx (2015), the NIS approach stresses that the flow of technology and information among the various actors are critical to the innovative process. The World Bank (2006, p. 16) defines Agricultural Innovation Systems (AIS) as "a network of organizations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organization into economic use, together with the institutions and policies that affect their behaviour and performance." This definition points to the different actors, their inter-relationship, and how they interact, share, exchange, access, and use knowledge within national and international agricultural frameworks. The AIS approach and the NIS approach both emphasize the need to consider and create meaningful interactions that are not only limited to the farm gate but throughout the entire value chain (Klerkx, 2015). Therefore, the AIS and NIS need the efforts and cooperation of all the actors and rules through which actors or participants interact. These rules may be linkages, infrastructure, and institutions. Thus, AIS and NIS systems are not stagnant but rather dynamic and subject to multiple changes.

For policy-makers, a good understanding of AIS and NIS can help identify leverage points for enhancing the overall performance and competitiveness of an innovation. In addition, it can assist in pointing out certain mismatches within the system, including both among the institutions and government policies (Schut et al., 2014). Specific policies that aim to improve communication or networking among the actors within the system are directed at enhancing firms' innovative ability, mainly how they identify and absorb technologies (Hermans, Apeldoorn, Stuiver, & Kok, 2012). AIS is embedded within the concept and ideas of NIS, and the AIS analytical framework helps in examining technological change in agriculture among various actors. One of the reasons that promoted the development of the AIS concept was to better understand how the agricultural sector of a country can better use available knowledge and interventions beyond the scope of research investments (Klerkx, Aarts, & Leeuwis, 2010).

The concept of NIS and AIS align with the goals of this study in various ways. As the current agricultural systems are seen to be inefficient in meeting the current global challenges such as food insecurity, poverty, reduced livelihoods and climate change, agricultural development programs through the cooperation of all stakeholders, need to come up with innovative ideas that can help counter some of these challenges (Hermans et al., 2012). Several governments in Africa and around the world and NGOs are working closely with research institutes to understand the potential of using emerging technologies in our agricultural systems. CSA and CIS are a few widely used approaches by many developing countries, especially those in Sub-Saharan Africa. The results of this study showed a significant shift from old traditional farming methods to newer ones. In Ghana, where CSA and CIS practices complement each other, ICTs and BDA tools are helping farmers have access to reliable climate information and weather forecasts, which help them base their farm management decisions on reliable data. AIS seeks to explain the process of innovation within the agri-food sector and how the actors, including both human and non-human actors, can make the best use of available resources to improve productivity for smallholder farmers while at the same time mitigating climate change hazards and greenhouse gas emissions. The diffusion of innovations theory, actor-network theory, and transfer of technology (Labarthe, Caggiano, Laurent, Faure, & Cerf, 2013) concept could help explain the transfer of information and innovation among the actors, and through means by which the diffusion and acceptance of technology occur. However, for the scope of this work, they are not very relevant in conveying the overall purpose of this research. Actor-network theory is most applicable to contexts where one's focus is analysing well-defined cases. The interactions between the actors are illustrated in the conceptual framework below

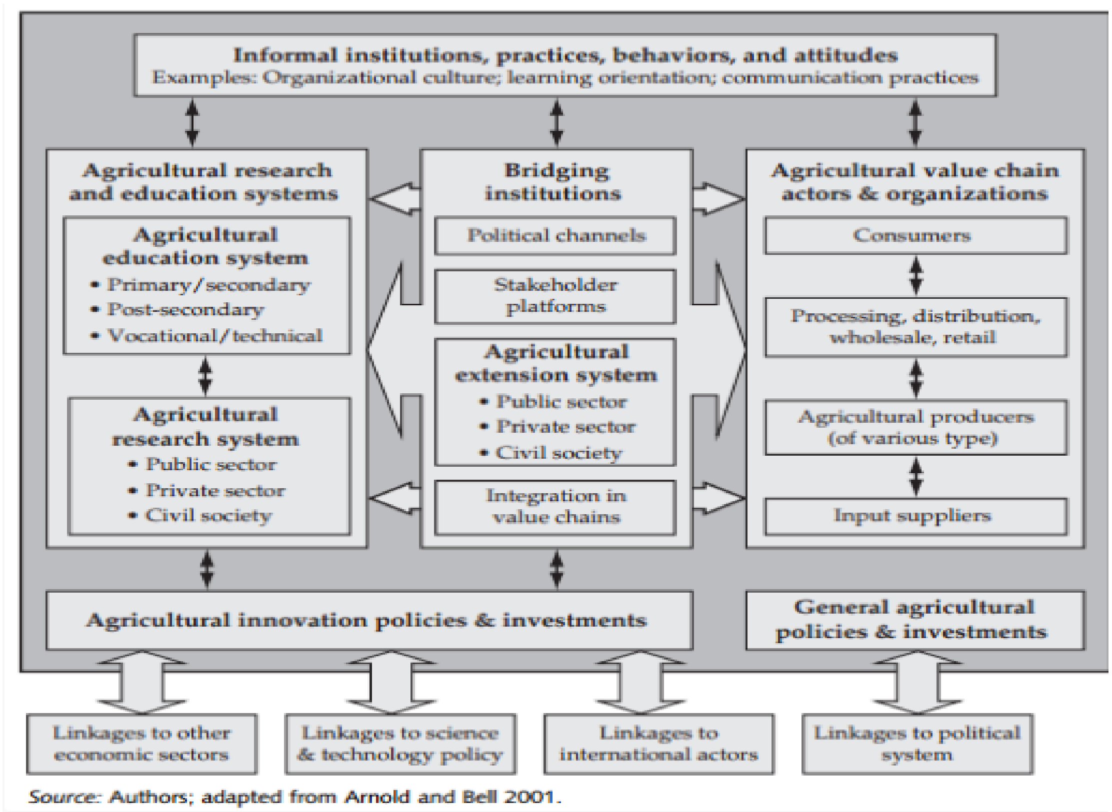


Figure 2. Conceptual Diagram of AIS (Arnold & Bell, 2001)

The conceptual framework depicts the primary actors in AIS, such as agriculture knowledge and ATPs, users, and intermediary institutions that interact among the actors possible. It also shows their potential interactions with each other and how they benefit from such interactions. All the actors are influenced by the agricultural policy context and the practices that hinder or support the innovative processes (Labarthe et al., 2013). It is, therefore, essential to understand that promoting innovations in agriculture is a process that requires the coordination and support of agricultural research, education, and extension. Such coordination helps foster innovation partnerships and linkages that create an enabling environment for agricultural development programs beyond the value chain (Rajalahti, 2009).

The success of AIS and NIS can be achieved if the right partners are brought together to establish a shared vision, opportunities to develop trust and understanding, a common language, processes of conflict management, a shared vision, support for collaboration and openness about costs and benefits (Hermans, Apeldorn, Stuiver, & Kok, 2012). Findings of this study demonstrate the need to have effective collaboration among the various actors when using new technologies to collect and analyze climate data for smallholder farmers with the aim of improving productivity and livelihoods. AIS can help identify the gaps that exist among the actors and explain the flow of data and technologies among the actors.

3.1.1 Use of AIS framework within NIS and It's Limitations

The AIS approach has become a trendy and widely used framework to analyze and explore coherent solutions to the many complex problems in agriculture (Schut et al., 2014). For example, Spielman and Birner (2008) used the AIS framework to identify the primary indicators for measuring the innovation inputs, processes, and outcomes. Their framework was initially adapted from Arnold and Bell (2001) and consisted of three key elements: (1) a business and enterprise domain; (2) a knowledge and education domain; and (3) bridging institutions that linked elements 1 and 2. Kamara et al. (2019) used the AIS framework to assess the institutional linkages in Azerbaijan from an innovation system framework. Their study assessed the effectiveness of AIS in the country by identifying patterns of innovation activities and the patterns of interactions among the actors. It further helped them to identify the constraints of these interactions. Mambo (2014) also adapted the AIS framework. It concluded that it constitutes the interrelationship among four main actors, which are the markets, researchers, and extension agents and how these actors are influenced by their economic, social, political, cultural, and institutional environments to determine the nature and type of agricultural innovations, and thus, the overall impact on the livelihoods of smallholder farmers.

The AIS framework may be necessary for providing the basis for analysing innovations and their usefulness in increasing the innovation processes in agriculture; however, it is viewed by many to have many limitations that divert its utility. According to Klerkx et al. (2012), one of its key weaknesses is the assumption that all actors have a common goal related to innovation. There is very little or no recognition given to the fact that the actors may have perspectives and goals which can probably diverge and conflict within the system. This needs to be particularly taken into consideration when assessing the participation, roles, and behaviours of smallholder farmers using new agricultural technologies such as those enshrined in this study.

Furthermore, even though the innovation system approach promotes the innovation and interaction of different actors, Hall et al. (2007) believe that there lie barriers and challenges in deciding which actor should work with whom. This challenge is because very few actors will miss the concepts outlined within the innovation system. At the same time, too many actors make the work rate unmanageable. It can be inferred from this that, although the involvement of diverse actors in the innovation process is essential, it is essential to consider the role of actors and how their participation may impact the desired results.

3.1.2 What is Innovation, and Why Innovate the Agricultural Systems?

AIS involves a wide range of actors who help to create, transfer or adopt innovation. They also advise and inform farmers about innovations. The governments' role is to provide strategic guidance and financial support to researchers, extension services, and advisors within the public and private sectors **(**Labarthe et al., 2013**)** and research infrastructures such as ICTs, databases, laboratories, etc. AIS actors are also responsible for implementing policies and regulations that affect the agricultural business environment. Farmers, private organizations and researchers within AIS are accountable for creating the innovations. At the same time, advisors and other intermediaries help diffuse the innovation on farmers and agri-food industries (Klerkx, Aarts, & Leeuwis, 2010).

Innovation is more than Research and Development (R&D), and it encompasses both the adoption and creation of innovation (Alston, 2010). Many innovations are seen to be process innovations at the farm level as they mainly relate to farm production techniques such as the adoption of improved seeds, precision farming technologies, intelligent ICTs, BDA tools, CSA, and CIS practices things. Some innovation systems such as improved seeds and irrigation technologies, agricultural machines, or buildings are categorized under product innovation for the upstream industry. The downstream sector also helps to generate product innovation such as food or non-products from agriculture such as the chemical industry. NGOs and charity organizations fund the innovation and provide information and advice to farmers and other stakeholders. Furthermore, markets and consumers finally play a role in providing signals for innovation, and the public's acceptance of the innovation supplied to actors.

Just as in other sectors, innovation in agriculture is the primary driver of productivity growth (Klerkx, 2015). Public expenditures on R & D are estimated to have a massive impact on agriculture total factor productivity growth and competitiveness (Alston, 2010; Alston et al., 2010). At the national level, innovation helps to improve competitiveness and economic development through the cooperation of actors. Innovations in agriculture at the national level also contribute to the diversification of emerging economies in developing countries (Alston et al., 2010**).** At the farm level, introducing innovations should lead to high-income generation, increased productivity, and a better allocation of resources. Innovation can also help improve the farm's environmental performance; however, new techniques can be risky, especially if they are not difficult to implement or not tailored to specific circumstances or if they fail to materialize on the farm and the market. Research showed that innovation in agriculture has been very successful in particular areas, such as improving the productivity of crops and the quality of some agricultural products. Still, for it to remain competitive, it needs to stay continuous (Klerkx, 2015). In some regions and countries in Africa, the challenge is to adapt from agricultural systems to difficult to manage environments. It should be noted that innovation in food sectors such as agriculture usually targets the changes in food consumption habits linked to higher participation of women in the labour force, higher income, health concerns, etc.

3.2 The Politics of Technological Innovation from AIS perspective

This section highlights how political influence and specific agricultural programs may affect using ICTs and BDA on climate data to improve productivity for smallholder farmers. The section discusses the influence of technology providers and insurance programs in agriculture and how these affect small-scale farmers' farming behaviours and outcomes.

3.2.1 The Influence of Agricultural Technology Providers

The gathering and analysis of climate data using ICTs and BDA in CSA is a relatively new concept. Therefore, it is expected that knowledge about their application and implications in agriculture is not widely spread. Although the use of BDA and related technologies in agriculture may seem like an innovative model that can solve most of the challenges faced by small-scale farmers; however, some scholars are very much critical of BDA and related technologies in agriculture as another technology hype that may fail to materialize (Wolfert et al. 2017). At the same time, the proponents of BDA propose that it may have passed the peak of inflated expectations (Needle, 2015). According to Ryan (2020), using and adopting these technologies may have potentially harmful consequences such as political interventions and wrongful or exaggerated power exercises. To better understand the technological hype of BDA use in agriculture and the consequences that may result due to exercises of politics and power on small-holder farmers, Ryan (2020) analyzed Brey's (2007) five distinctions of power relations and applied them to the use of big data and related technologies in agriculture. The five forces discussed are manipulative, seductive, leadership, coercive, and destructive power (Ryan, 2020). Ryan (2020) showed that ABDA and CSA could be used as a form of controlling and manipulative power to trick farmers into believing the powers of these technologies, the consequence of which is cheap land grabs and acquisitions. With the ongoing hot topical issues of climate change, food security, and improved livelihoods, poor and marginalized small-scale farmers can be easily tricked. They can succumb to the pressures of Agricultural Technology Providers (ATP). This type of trickery is described by Brey (2007) as seductive power. Seductive power is a manipulative form of power and control. Farmers are pressured into choosing situations that they would not have otherwise chosen on their own accord. While using specific technologies and equipment on the farm helps farmers make better farming decisions, the use of these technologies on farmlands owned by farmers who have little or no knowledge about using these technologies should be highly restricted. Such farmers should not be tricked or pressured to accept the installation and the use of these technologies on their farms. Ryan (2020) explains various techniques used on the farm to exert power on farmers. An example given is the installation of monitors and limited access to farmland and farm machinery, examples of seductive power control in agriculture. Going further with a critical analysis of CSA and ABDA technologies, Mark Ryan showed that ATPs exercise leadership power on farmers by pressuring them to use CSA and ABDA technologies on their farms without any informed consent (Ryan, 2020). Coercive power is exercised in CSA when farmers are given the choice of either abiding by the policies and requirements of ATPs or risk losing ABDA technologies (Wolfert et al., 2017) because of the fear of harsh economic and perhaps legal reprisals. Mark Ryan (2020) critically analyzed the five types of power and demonstrated how they could exercise power and control in the agricultural industry.

When we carefully think about the context of the production of big data and analytics, we precisely should evaluate what critical data studies scholars have done when they highlight the concept of big data as it is framed and understood by people from different social and technical contexts (Edwards, 2010; Gitelman & Jackson, 2013). According to Lev Manovich (2001, p. 24)," data do not just exist; they have to be generated." Critical social scientists have proposed that social contexts, particularly those that emanate from the questions of justice and ethics, cannot be treated as separable from big data as a technical accomplishment (Busch, 2014; Elmer et al., 2015). For example, many scholars have explained to what extent' crowdsourced' information primarily benefits marketers and other stakeholders within the elite group rather than the data subjects (i.e., the crowd contributing to crowdsourcing) (Qualman, 2009).

As a result of the ongoing unauthorized access and use of users' data, Bronson & Knezevic (2016) propose that a critical data studies framework is that allows for the careful examination (and investigation) of the possible ethical implications from big data in the realm of food and agriculture (p. 2). Therefore, it is paramount to know and understand who retains ownership of data collected for agricultural use, what privacy implications there are with the data gathered by ICTs, and who ought to access the data generated by mobile phones and other tools. These are essential considerations to keep and address when using users' (farmers') data in agriculture to maximize production and sustainability. Various scholars posit that exploring and assessing the ethical implications of big data in agriculture should not only be built on critical data studies, but it should also extend on food studies to understand the effect of technologies on farmers and food systems (Clapp, 2012; Koc et al., 2012). Bronson & Knezevic (2016) predict that powerful corporations may perpetuate particular agricultural systems for the disproportionate gain of powerful agri-food productions and big data technologies.

3.2.2 Implications of Certain Innovation Programmes on Small-Scale Farmers

In an era where technologies are disrupting almost every sphere of our lives, data collection technologies, the increase in computational power, and efficient algorithmic models play a role in lowering data collection and processing costs (World Economic Forum, 2018). By harnessing the transformative power of BDA in agriculture, agricultural and non-agricultural financial institutions can lower transaction costs through the elimination of the need to embark on field inspections (World Bank Group, 2017) and help mitigate specific agricultural risk. BDA can be used by both index and conventional insurance applications to reduce the risk of providing insurance products to farmers. Big data derived from sources such as crowdsourcing, crowd-mapping, satellite, drone-based-imaging, and cellphone apps are mainly used to improve modelling (World Economic Forum, 2018). Numerous studies show that farmers' adoption of insurance products directly influences investments, improved livelihoods, and efficiency (World Bank Group, 2017). One example of a BDA insurance program used in CSA is Mobbinsurance. Mobbinsurance was launched in 2014, and its role is to offer crop insurance and market access to smallholder farmers. It is a South-African start-up that gives farmers the ability to sign-up for the insurance program through their mobile phones. Once they sign up, Mobbinsurance uses satellite technologies owned by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) to monitor their crop and weather. Mobbinsurance works based on the South African National Space Agency partnership and NASA and ESA (World Economic Forum, 2017). According to the World Economic Forum (2018) projection, by 2030, approximately 200-300 million farmers worldwide could be provided with insurance solutions. When many such farmers are provided with insurance solutions through BDA, this could generate 40-150 million tons of additional food and 15-70 billion dollars in extra farming income (World Economic Forum, 2018, World Bank Group, 2017). Farmers will, therefore, indirectly benefit from improved health and nutrition. In addition, recent studies indicate that households that face severe environmental and economic conditions will not restrict themselves from having proper meals and spending money in buying essential family needs when a certain amount of money or income is guaranteed through some form of insurance policy (Castillo, Boucher, & Carter, 2016).

The above projections testify that low-cost methods for aggregating and collecting farm data through farmers' participation and collaboration with ATPs and insurance providers will be essential for scaling insurance policy solutions effectively and quickly. In addition, farmers' improved access to weather information through education programs using ICTs will be crucial in enabling them to make more informed farming decisions about what crops and products are available to them and how purchases could be made (Karki, Burton, & Mackey. 2020). Nonetheless, it is essential to highlight that farmers' access to essential insurance is not sufficient enough to help them maximize their productivity and livelihoods. In essence, farmers also need to have (direct) access to farm inputs, infrastructure, and other services to enable them to take full advantage of these products (Velante, 2015). One potential benefit is the readiness and willingness of farmers to take certain risks. That could mean increasing farm investments, adopting and implementing innovative farm practices, or even trying new inputs. BDA in CSA is helping farmers to have access to insurance benefits. Farmers engage in providing farm information to ATPs who share this data with insurance companies. In return, farmers get certain benefits (World Economic Forum, 2018).

Though ICTs and BDA in agriculture are helping to scale insurance products, there are, however, associated risks that need to be highlighted. Conventional and index insurance rely on specific models to determine the type of payout farmers get. For example, index insurance primarily relies on accurate agronomic models to calculate the payout to farmers; in this case, if the provided data is inaccurate, insurance costs can rise significantly (World Economic Forum, 2018). Furthermore, farmers use specific inputs without having the required skills or training, which may significantly lead to negative consequences. Generally, most insurance programs target specific livestock, crops, or fisheries. By targeting these agricultural products, insurers can influence farmers in only producing those insured items, thus reducing farmers' incentive to diversify their farming activities (Rima, 2015). Also, insurance programs may potentially discourage investments in vital on-farm infrastructure (Velante, 2015). For example, when insurance products target rain-fed regions, this may reduce investment in irrigation farming.

4. Methodology and Research Design

This section presents the methodological approaches that are employed in carrying out this work. The study used two qualitative data collection techniques. As part of the efforts to meet the goals of this study work, a case study research design technique was used. The case study approach was intended to identify and explore a specific case in a broader context to draw generalizations, establish relationships, and map out the similarities and differences between variables of interest. The central basis for data collection followed a two-phase methodological approach. One of which was a systematic review, and the other was in-depth qualitative expert interviews. This section presents the research strategy used as a framework for data collection and the methods employed to collect data. It starts by introducing the research design and then explaining the two main techniques employed in carefully gathering the data to generate findings and the subsequent analysis.

4.1 Research Design

This study employed a case study research design. A research design provides a framework for the collection and analysis of data (Bryman, 2016). The fundamental idea of a case study research design approach, as put forward by Alan Bryman (2016), entails studying and analyzing a case thoroughly. Stake (2011) also explains that case study research is mainly concerned with the underlying natural complexities of a case in question. Many best-known social science studies are based on this kind of research design. It is imperative to establish a first-hand understanding of the meaning of the term 'case' before understanding the rationale for why a case study research design was employed in this work. Bryman (2016) describes the term 'case' as something associated with a physical location such as a country, organization, school, or community. The central idea for a case study is to have an intensive exploration and examination of a setting or phenomenon.

Ghana has been used as a case of interest due to its ambition to digitize its economy and the ongoing efforts to digitize agriculture. To comprehensively address the research theme, it was paramount to choose a single case of interest that closely matched the research goals. Since the intended data collection methods were qualitative, a case study design was deemed the most suitable due to its close alignment and association with qualitative research by many researchers. Many exponents of this research design are often inclined to qualitative methods such as interviewing, document analysis, and participant observation. These methods are instrumental in obtaining an intensive, detailed examination of a case. Although case studies are generally associated with qualitative methods, it is also a frequent site for the use of both qualitative and quantitative research (Decuir-Gunby & Schutz, 2017; Greene, Caracelli & Graham, 1989). Other research designs such as longitudinal design and cross-sectional design can be highly applicable to this research. However, these approaches have not been used here due to the time factor and the limitation of resources. Single case studies are essential because they help reveal crucial features about the nature of a case and describe these features, draw relationships among them, and map out their differences. It was hoped that choosing Ghana as a single case for this study will help understand the use of ICTs and BDA on climate data in CSA in a broader context and how this applies to the African agricultural sectors and global contexts.

According to Bryman (2016), a good case study follows a well-designed case study protocol. The case study protocol helps to highlight the essential procedures that were planned before carrying out the case study. In addition, it gives an overview of the research question(s), the scope of research, and the focus of study (Rashid, Rashid, Warraich, Sabir, S, & Waseem, 2019**;** Eisenhardt, 1989). The protocol used to conduct the case study of this study is given in table 1 below.

Phase	**Stage**	**Activity**	**Purpose**
Phase 1	**A**. Getting started	- Define the research question(s) - Possible a priori constructs	- Focuses research efforts - Provides better grounding for conducting research procedures and measures

	B. Case selection	- Specify the population of interest - Determine relevant theories - Decide the sampling techniques	- Ensures theoretical flexibility - Constraints extraneous variation and sharpens external validity
	C. Crafting of protocols and instruments	- Two data collection methods - Qualitative research	Triangulation of data helps strengthen research findings
Phase 2	a. Entering the data collection field	- Iterative data collection and analysis - Flexible opportunistic data collection	- Speeds the analysis - Eases emergent themes

	b. Analyzing the data	- From within the same case - Possible cross-case analysis	- Helps build familiarity with data - Opens doors to look beyond initial impressions
Phase 3	Enfolding the literature	- Comparison with similar literature - Comparison with contrasting literature	- Helps sharpen construct definition - Builds internal validity and raises the theoretical level

Table 1. Case study protocol

4.2 Research Methods

According to Bryman (2016), a research method is simply a technique for collecting data. This technique can be in the form of interviews, self-completion questionnaires, etc. The data collection technique used in this study employed a two-phase methodological approach to collect rich qualitative data through expert interviews and a systematic literature review. Both of these methods are qualitative. Although quantitative data collection techniques could be applicable, the compelling nature of the research topic and the research question under study required heavy use of qualitative data and thus, a quantitative approach has been undertaken after a specific research design was chosen as a framework for data collection and analysis, these steps involved methods that allowed for collecting data to be used as a focal point for drawing findings and interpreting those findings in light of the literature review theoretical framework.

This work used a systematic literature review and expert interviews as the two main methods for data collection for various reasons—the nature of the research questions and the research topic in general. The nature of the research topic and research question can be compressively addressed using qualitative research. Conducting expert interviews and reviewing large enough scholarly articles, policy documents, and other valuable data sources provide very rich data suitable for analysis. Expert interviews also allow for a detailed and intensive exploration of a topic by actively engaging the interviewees and asking them relevant questions while interviewing them. One of the most used methods in collecting qualitative data is through interviews. Many researchers use expert interviews because they allow for maximizing the strength of other qualitative data and use expert knowledge and experience as sources of evidence to answer research questions (Decuir-Gunby & Schutz, 2017). Since this study seeks to understand whether ICTs and BDA in CSA can help sustainably maximize small-scale farmers' productivity, having interviews with an expert in the field is valuable for getting detailed responses. These experts are not agricultural technology providers who may only possibly argue for the relevance of their technologies to the farming sector. However, these experts have experienced working as agricultural and small-scale farmers in Ghana and many African countries for many years and have first-hand knowledge. The amount of time they spent working with agricultural technologies and small-scale farmers made them suitable as interview participants. Combining data generated from interviews, systematic review, and the case itself helped triangulate data to reach more credible findings and conclusions.

Field visits, interviews and direct interaction with smallholder farmers in Ghana would have contributed immensely to get more insights from farmers, but this was not possible due to the pandemic, time factor and insufficient resources. Conducting field visits and having direct interviews with farmers could prove vital in accumulating qualitative data from smallholder farmers about their experience with the newly introduced innovative technologies in their farming methods. Nevertheless, field visits and direct interaction with farmers were not possible in current circumstances. Furthermore, factors such as time, language barrier, and lack of enough financial resources also made this impossible. Again, to talk to local farmers, the service of an interpreter would be needed, which could incur additional costs and burdens.

A systematic literature review was seen as the most suitable alternative in the absence of field visits. Instead, one could directly talk to smallholder farmers. While one can get a very detailed explanation and responses from experts within CSA using ICTs and BDA, what one cannot get is the perspective of farmers themselves and the evidence gathered by other researchers and organizations. Therefore, to supplement the data obtained through in-depth expert semi-structured interviews, a systematic review was chosen. A systematic review is a form of literature review that helps to answer a specific research question. It involves conducting a comprehensive literature search and critical appraisal of studies that have been gathered. It also helps to combine valid studies using appropriate statistical techniques. According to Postavaru and Cramer (2016, p. 1), systematic (literature) reviews are considered one of the best sources of evidence for both qualitative and quantitative data because they help show the results from previous research. They can also be used in explaining existing phenomena (McEwan, 2017).

This section provides information by which the validity of this study can be assessed. First, it explained how the data for this work was collected and analyzed. It was crucial to carefully choose the research methods for this work because the methods one chooses can affect the results and even impact the subsequent analyses of the findings that may later follow. Unreliable methods often produce poor results and lead to the misappropriate interpretation of a study's findings (Decuir-Gunby & Schutz, 2017). A systematic breakdown of the procedures used in conducting interviews and systematic review, the participants' interviews and how they were selected, the interview protocol used, and the model and protocol used to do a comprehensive systematic review effectively.

4.2.1 Interviews

Qualitative semi-structured interviews were conducted with experts working with climate data within CSA using ICTs and BDA. A semi-structured interview was used because it allows for a broad examination of a case using a flexible questioning format. The research question under study and the overall research topic could be best addressed using semi-structured expert interviews. Structured and unstructured interviews could have been used. However, neither of these two would have offered any significant help in addressing the research problem. A structured approach to interviewing is mainly used when a researcher addresses a quantitative research problem. It uses a standardized format of questioning (Bryman, 2012). Unstructured interviews can help conduct focused group interviews. For example, an unstructured interviewing technique would have been used to interview or discuss with smallholder farmers.

Semi-structured interviews are effective data collection techniques for gathering qualitative, open-ended data. They are also helpful in delving deeper into participants' thoughts, beliefs and feelings about a particular topic, idea, or concept. Sometimes they are even used to dig deeper into personal and sensitive matters (Bryman, 2012). The scope of applicability of the semi-structured interviewing technique made it suitable in answering my research question.

The total number of participants for the interviews was six (n=6). A large amount of data would have been gathered if there were at least ten (10) interviews. Notwithstanding, some of the people contacted either never responded or did not show up on the scheduled interview day. Thus, the total number of people interviewed was six (6). Participants were selected using two non-probability sampling methods: purposive sampling and snowball sampling. Purposive sampling and snowball sampling were used to determine participants for two reasons. One, because of the nature of the research. Two, difficulty in finding suitable experts to interview. A purposive sampling technique is a way of selecting samples based on the topic of interest. They are chosen by the researcher based on their knowledge about the study and the population (McEwan, 2017; Bryman, 2012). A snowball sampling technique was used since reaching out to experts sometimes needs a recruitment process. A snowball sampling technique is used when it is difficult for a researcher to reach out to subjects of interest. It is a strategy that uses the connection of existing study subjects to recruit future issues from among their acquaintances (Bryman, 2016).

In this study, interview participants are all experts in smart agriculture, climate services, big data analytics, and climate-smart agriculture with significant years of research experience in agriculture. They had direct on and off-field interactions with smallholder farmers in many African countries. Three of the participants are from Ghana. Two work with the Agriculture Communication & Youth & Women in Agribusiness Development Professional, Ghana and one works with the FAO Ghana branch. Two of the remaining four interview participants are senior researchers who currently work with International Research Institute for Climate and Society (IRI) and closely collaborate with CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The other two work with the Consultative Group on International Agricultural Research (CGIAR). CCAFS is a working branch under CGIAR.

The interviewees were contacted via email to confirm their participation. Format for the interview was communicated before starting the interviews, and ethical considerations such as recording the interviews and transcribing them were cleared at the on-set. Three of the participants agreed to have the interviews recorded. The other three participants explained that to record the interviews, a formal written request should be sent to their supervisors within their organizations, who would have to approve those requests—all that procedure required waiting time. To avoid delay, they agreed to have interviews on the condition that notes can be taken, but no recording was to be permitted. The interviews were conducted in an informal setting where discussions were primarily informal. The relaxed nature of the interviews allowed for extensive discussions touching various aspects of the interview questions. The interviews were conducted through Zoom and Skype, and three were recorded and later transcribed. Each of the interviews lasted between 20 minutes and 1 hour. The average minute for the interviews was approximately 45 minutes.

Upon completing the interviews, the interview transcripts and notes taken during the interviews were shared with the participants as a research validation step. The participants were asked to attest to the accuracy of the interview transcripts and the taken notes. The validation phase was needed to avoid working with erroneous data that can interfere with the validity and credibility of the research's findings. The interviewees confirmed their respective interview transcripts and notes as very accurate via email. After their confirmation, the interview notes and transcripts were then coded and analyzed in light of the literature review and theories. The coding approach used to code the data from interviews is thematic coding. In qualitative research, coding is about defining the data you analyze and understanding what the data is about (Gibbs, 2007). Coding involves identifying themes, paragraphs, phrases, or other data items in the text, and looking for concepts and building the relationship between them.

Thematic coding was used because the interview protocol was made into central themes to get relevant information that accurately and closely answers the research question. With thematic coding, related concepts are grouped into the same themes and relationships that exist between those concepts can be established. The table below summarized the coding process.

Steps	**Procedures**
1. Taking notes	The six interviews were analyzed. This process involved writing comments at the margin of the interview transcripts, highlighting important pointers, and underlining specific themes. In addition, as the data was being explored, initial reactions to the interview material were noted.
2. Summarizing notes	During the daily coding process, the reactions to the main noted points were considered, comments and highlighted texts were compared and contrasted, shared perspectives on discrepant viewpoints, and then developed a summary sheet.
3. Verbatim text re-wording	Metaphors were generated from the summary sheet. In addition, phrases that represented the interview responses of the participants were formulated and summarized. Creswell (2013) terms this as the preliminary stage in the coding process.
4. Making Comparisons	The key phrases were compared and contrasted (Miles, Huberman & Saldana, 2014) and were grouped into categories. This stage helped reduce the data to a manageable form, as similar phrases were combined and overlapping categories were equally merged.
5. Developing codes	Creswell (2013) remarked on the importance of reducing the data to eliminate redundancy. Therefore, similar phrases and overlapping categories were continually merged, and category headings were reformulated. From this phase, themes were developed based on the data (Miles, Huberman & Saldana, 2014).

6. Reporting results and analysis	Final codes and themes that were generated were objectively presented and analyzed in light of theories and literature.

Table 2. Coding and interview interpretation process

Questions for the interview were formulated using the below interview refinement protocol. This refinement protocol was prepared as a guideline for developing the interview questions and conducting the interview.

PHASE	**PURPOSE**
PHASE A: Ensuring interview questions are in line with the research question	To map the interview questions to the research topic and research question
PHASE B: Following an inquiry and focused based questions	To construct interview questions that balance inquiry with detailed conversations
PHASE C: Receiving feedback on interview protocol	To obtain detailed feedback on interview questions
PHASE D: Piloting interviews	To pilot the interview protocol with a minimal sample size of 3 (even with n = 2)

Table 3. Interview refinement protocol

The interview protocol consisted of questions drawn from themes within the research questions. Questions were made such that discussions were flexible and can expand to touch on a wide range of issues pertinent to the research topic. The interview questions used as a guideline for conducting the interviews can be found in the appendix. The central topics of discussion were climate-smart agriculture, climate data, climate services, ICTs, big data analytics, sustainability, challenges, smallholder farmers' productivity, data quality issues, and power relations hindering small-scale farmers and agricultural productivity as a whole.

4.2.2 Systematic (Literature) review

Before outlining the purpose of this systematic review, it is worthy of mentioning that previous qualitative studies have been conducted on digital agriculture, CSA, BDA, climate services, ICTs, and the effect of these farming approaches on smallholder farmers and climate change mitigation. In preparation for conducting this systematic review, a considerable number of past research papers have assessed the use of ICTs, BDA within CSA, and smart-farming in general. However, these reviews were constrained based on various intervention characteristics. For example, many reviews only included studies mainly focused on ICTs use in agriculture. In contrast, others concentrate on CSA and its role in improving climate conditions and farmers' productivity. However, very little research primarily focused on whether these different tools and farming techniques can benefit smallholder farmers by scaling up their productivity, income, and livelihoods.

In conducting this systematic review, searches for potential articles and documents were conducted in various scholarly databases. The databases used to perform the probes and the keywords used in each database are summarized in Table 1d**.** Searches were conducted using search eligibility criteria and exclusion criteria based on the research question and the research topic. The criteria used to conduct searches for relevant articles and documents were based on a structured, systematic review protocol designed purposely for this work. As noted by Creswell (2013), a systematic review protocol helps the researcher to have a scope for the research and limits the search and review to only the articles that are deemed most relevant. Exclusion and inclusion criteria used to conduct this review were the same as those used to perform the literature review. A literature review was first undertaken to understand the past and current status of the research topic and question under study in this work. Based on the literature review findings, a systematic review protocol helped guide the direction of the review process. It helped broaden the overall understanding of the current and past research, which allowed the formulation of solid search criteria.

The various concepts that the research question covers prompted the need to use Boolean queries, Phrase queries, and Keyword queries on the databases used to return more relevant articles and documents. These queries all helped narrow down the results to relevant articles. Thus, the time spent reviewing the produced reports was considerably reduced. In addition, logs of keywords and search terms were recorded during a systematic review. The table below summarizes the databases used and the key search terms used in each database. The searches were conducted over six (6) months, from January 2021 to June 2021. Each article was subjected to three main conditions: (a) title elimination, (b) abstract elimination, and (c) full-text elimination. Table 4 below presents the databases and their search terms.

Databases	**Search Terms**	**Search Index**
1. Science Direct (https://www.sciencedirect.com/)	Smart-farming in Ghana, IoT and Big Data, ICTs in Climate-smart Agriculture, Big Data, Agricultural Productivity, Small-scale farmers, Climate information, Impact, Sustainability, Climate, Africa, Kenya and Ethiopia, Rwanda, Senegal, Interventions, Change theory, innovation systems theory, analytical frameworks, agricultural technologies, political economy	AND and OR as inclusion criteria. NOT as exclusion criteria
2. Sage Journals (https://journals.sagepub.com)	Digital technologies, big data, agriculture, smart-farming, small-scale farmers, smallholder farmers, Africa, Ghana, productivity, sustainability, data	AND and OR as inclusion criteria. NOT as exclusion criteria

3. Research Gate (https://www.researchgate.net/)	Political economy, big data analytics, climate information, farmers, smallholder farmers	AND and OR as inclusion criteria. NOT as exclusion criteria
4. B-ok.org (b-ok.org)	Big data, IoT, Agriculture, Implementation practices, ICTs, Income	AND and OR as inclusion criteria. NOT as exclusion criteria
5. SCI-HUB (https://sci-hub.se/)	Big data and agriculture, Impact of ICTs in Agriculture, Climate-smart agriculture, Small-scale farming, smart--farming	AND and OR
6. CGIAR (https://www.cgiar.org/)	Climate-Smart farming, Climate-smart agriculture, Small-scale farmers productivity, Ghana, Climate information, Improving Agricultural Productivity, farmers, livelihoods	AND, OR, NOT
7. CCAFS (https://ccafs.cgiar.org/)	Climate-Smart Agriculture, Smallholder farmers, small-scale farmers, Africa, Ghana, Rwanda, ICTs in Climate-Smart Agriculture, Livelihoods, income	AND and OR

8. FAO (http://www.fao.org/home/en/)	Climate-Services, Climate Information and Productivity, Climate-Smart Agriculture, Smallholder farmers, small-scale farmers, Sustainability, Productivity	AND and OR

Table 4. Summary of databases and search terms

This study's overall purpose was to understand better whether the use of ICTs and BDA technologies on climate data can sustainably improve the productivity of smallholder farmers using Ghana as a case of interest. In addition, to establish a better understanding of the relevance and the effectiveness of the studies that were reviewed, an assessment was done to determine whether there are certain conditions under which independent variables of climate data, ICTs, BDA, and external factors such as political intervention and technological triumphalism more strongly or weakly casually influence the dependent variables of agricultural productivity and sustainability. The specific moderators that were assessed included: (a) impact evaluation, (b) farmers' attitude, (c) the type and nature of ICTs and BDA technologies in use, (d) the role of stakeholders, (e) the types of impact evaluation measures used to quantify the effect of these novel farming approaches on smallholder farmers.

For an article to be included in the systematic review, a study needed to examine the impact of climate information on smallholder farmers' productivity in CSA using ICTs and BDA. As this review was mainly concerned with technological interventions in farming, studies that focused on anything outside the scope of the research question for this subject were eliminated. The articles were delimited to those published in the English Language and those studies conducted in Ghana and other African countries of interest. In a few cases, specific papers from North America and other countries were reviewed; however, these articles were very few.

Articles that met the eligibility criteria were extracted and coded independently concerning specific moderators. The moderators assessed were based on a scoping review so that pertinent characteristics reported in past works on improving the productivity of small-scale farmers using climate-based information using BDA and ICTs could be identified. This step was conducted in preparation for the systematic review. To reduce data heterogeneity and improve the interpretability of the findings of this review, studies that focused on climate services, CSA, digital agriculture, ICTs and BDA and smallholder farmers were pooled into one set of criterion variables to understand smallholder farmers' productivity as a target or dependent variable. Pooling studies using this technique reduced heterogeneity and helped identify how these agricultural practices impact sustainably and productivity.

The literature search from the databases listed in table 1d above returned over 1000 articles. The hand searches of specific journal articles returned 180 pieces, and the ancestry search of the reference list returned 54 articles. In total, over 1224 articles were returned from the databases used to conduct the literature searches using a combination of keywords and phrases. As there was insufficient time to review all the articles that were returned from the databases, the top appearing articles and documents were considered. The papers were first subjected to the elimination criteria, and duplicates or very similar reports were further eliminated. By the end of the elimination process, a total of 88 articles were included in the systematic (literature) review. In summary, the following steps were followed during the review: (a) formulation of the research question, (b) developing a review protocol, (c) conducting literature searches, (d) selection of studies and assessment of the study of study quality and relevance, (e) extraction of data and synthesis of relevant studies, (f) result interpretation.

4.3 Limitations

Despite the contributions of the systematic literature review and interviews, this study is not without its limitations. First, having field visits to talk to experts directly and smallholder farmers in Ghana would have been a great source of qualitative data and quantitative data. This process was, however, jeopardized due to the pandemic, time factor, and limited resources. For example, organizing workshops and household surveys with experts and farmers to assess the views of farmers and experts on the use of ICTs and BDA on climate data in CSA could have yielded more concrete qualitative and quantitative evidence. Also, the workshops could have allowed the simulation of these technologies on climate data which can later be used to assess how farmers could understand the weather forecasts and act on them to make farming decisions. The absence of such workshops and field visits were compensated with reviewing past research and documents where such practices were used. Systematic reviews allowed for the proper assessment of the results of those studies, including impact evaluations. However, except for the few cases presented in this research, it was not easy to find specific cases to study.

Furthermore, the participants for the interview were limited to a sample size of six (6). Larger sample sizes for expert qualitative interviews often provided rich and compelling data for further analysis and interpretation. However, to get the most out of the discussions, experts were carefully selected. The interviews were conducted so that large enough relevant information was extracted from the participants. Three of the interviews were recorded, while the other three were not. The interviews that were not recorded caused a challenge in capturing and noting down everything that was discussed. In addition, the network quality of two of the participants was terrible, which led to a loss of specific essential elements. Participants were taken aback at later stages of the interview to complement these setbacks. Points that were not clear due to the network were revisited. Also, further articles were reviewed to compare and validate the information given by the interviewees.

5. Results/Findings

This section presents the findings or results from the interviews, systematic review, and case study. A brief background is first provided on Ghana to rationalise and contextualise it as the leading case of interest. Then, within Ghana, two specific cases are picked and reported, supplemented by an outside case report in Senegal. These cases are the Esoko platform, a case study report on smallholder farmers in Northern Ghana, and a case report on using ICTs on climate data in Senegal. Finally, findings from the interviews and systematic review are presented in the table. A written contextualizing of the results is subsequently presented.

5.1 Case Studies

Much difficulty was met in trying to find cases to review during this study. Therefore, an approach that was taken was to conduct a general case study in Ghana while focusing on critical elements relevant to the scope of this work. In doing so, three use cases are studied and presented. The results from these cases are presented in the following sections.

5.1.1 Context: The Case of Ghana

Ghana is a country in West Africa situated on the coast of the Gulf of Guinea. It is relatively small in terms of land area and population; however, it is one of Africa's leading countries in terms of economy. The country's development is partly due to its natural wealth and partly because it was the first country in African to achieve independence. According to the 2019 population statistics, Ghana has a population of about 30.42 million. The three major geographic regions of Ghana are the coastal areas, forest regions, and the northern savanna (Maier, n.d). The smallest of these regions is the coastal zone which is traditionally a region of fishermen and small-scale farmers. Farther inland, the forest region occupies one-third of the country and has relatively large states rich in agricultural lands. The relief throughout Ghana is low. It has elevations that do not exceed 3,000 feet. In the southwestern, northwestern, and extreme northern parts of the country is a dissected peneplain made up of Precambrian rocks about 540 million to 4 billion years old. The interplay of two air masses majorly determines Ghana's climate. These air masses are the hot, dry continental air mass that runs over the belts of the Sahara and a warm, humid maritime tropical air mass that stretches over the South. The economy of Ghana consists of private and public enterprises (Maier, n.d). Agriculture contributes almost one-fifth of this economy. Agriculture, forestry, and fishing employ more than half of the population of Ghana, and Cacao, which is grown commercially for its seeds and cocoa beans, are cultivated on more than one-half of Ghana's arable land. These two crops are significant sources of the country's export revenue (Maier, n.d).

According to Coulibaly (2018), Ghana was among the top 10 fastest growing economies globally in 2018 and is currently the second-largest economy in the West African sub-region. Over the past years, the country has made significant progress in reducing poverty. However, its success in accomplishing poverty reduction has been unbalanced. Substantial inequalities still exist, especially the disparity between the South and the north. Most of the population of Ghana are impoverished and live on less than 1 dollar a day. It is estimated that about 24.2% of the population lives below the poverty line. On the Human Developmental Index of the United Nations Development Program, Ghana scores 140 out of 189 countries. The current inequality gap between men and women, especially in their access to resources for farming or setting up a business, continues to be very high. Current estimates show that what the richest men in Ghana earn in a month is far more than a one-thousand-year earning of the poorest women. A girl from a poor background is 14 times more likely to go to school than a wealthy family (Ghana Statistical Service, Ghana Health Service and ICF International, 2015). Although the real tragedy of Ghana and many other African countries lies in the fact that they possess resources to end hunger and poverty for the impoverished people of their nations and close the gender and digital disparities that are breaking the society apart, they are failing to act wisely and strategically. These tragedies are suffered mainly by poor farmers whose daily income and food come from subsistence farming. Considering the role of climate on farmer's productivity and the innovative farming practices that are currently being implemented in many African countries raises the question of whether digital tools and big data analytics technologies could be used on climate data to deliver impactful forecasts to smallholder farmers to improve their farming decision making and subsequently improve their farm productivity? Below is a case of Ghana Oxfam and the impact the Participatory Integrated Climate Services for Agriculture had on a case study on farmers in northern Ghana.

5.1.2 Case Study 1: Esoko's use of ICTs for Data Collection and Dissemination

Small-scale farmers contribute more to Ghana's agricultural production. However, despite their contribution to the agricultural sector, these farmers have minimal access to critical information underlining the complex global food chain, thereby preventing them from fully increasing or maximizing the value of their crops. Esoko is a company in Ghana that seeks to address this problem by using data analytics tools and ICTs to reach out to farmers. It uses multiple data sources, including open government data, to enable or help farmers make better farming decisions. However, the provision of information to smallholder farmers is not limited to Ghana. So, Esoko is helping to replicate this in other developing countries, encouraging new organizations to enter the market to provide similar services to farmers. For example, Esoko currently focuses on assisting the farm with access to price information for their crops (Esoko, n.d).

Since 2008, Esoko has been helping various enterprises to manage their rural communities. The Esoko platform has transformed its focus from providing content services to farmers to provide robust data collection and digitalization tools, biometric profiling, analytics, and communication services. Esoko has further introduced additional services such as digital credit, insurance, payments and transaction services. Two main pathways are used to deliver the services mentioned above; (a) Data collection and profiling, (b) Service delivery. For people looking to profile, register people, digitize agriculture supply chains and social protection programs, conduct GIS mapping or engage in climate-smart content, weather, market information, agronomic advisory services, extension services, Esoko helps in these areas (Esoko, n.d).

Esoko has been using the mobile phone to provide market prices through SMS to smallholder farmers on specific development programs. It aimed to understand how the emergence and use of mobile phone technology in Africa could improve rural communities' lives across the continent. Although this was their initial goal, Esoko has developed other digital tools and services to help propel agribusinesses and development programs to reach rural communities with digital solutions and services to uplift their livelihoods (Schalkwyk, Young & Verhulst, 2017). Esoko connects over 1 million farmers to agricultural services, including but not limited to weather forecasts, agronomic advice, insurance coverage. All these services are transmitted using various channels such as SMS, voice messages, and call centres. Research shows that such services may improve farmers' income by 10%. In addition, Esoko functions as data collectors, and they tirelessly work hard to provide good quality data to farmers. Having over years of experience collecting data across Gahan, Esoko has implemented and carefully tailored their mobile technology and deployment capacity. In 2018, a mobile-based data collection tool called *Insyt* was launched. This tool helps individuals and organizations conduct mobile surveys, monitor and measure project progress across various sectors (Schalkwyk, Young & Verhulst, 2017).

One of the reasons for the creation of Esoko as a company was to fill an identified gap or market failure in the Ugandan agricultural sector. Such market failures are attributed to farmers' lack of access to weather or market information. Esoko has therefore sought to counter similar shortcomings in Ghana. Ghanaian farmers mainly were compelled to trade their produce at low prices when they tried to seek information concerning weather, data on rainfall in particular, and these farmers are vulnerable to climate variations. While farmers could not access valuable weather and market information, the information did exist from different sources. However, the inefficiency and costly nature of the extension services tasked to deliver such information subsequently led to the emergence of Esoko to bridge the gap by providing farmers with the available information they require. The offerings Esoko delivers to farmers include automated mobile phone alerts containing agricultural and economic information that is usually sent as SMS and voice messages. These automated alerts include weather forecasts, crop production protocols, field manuals, planting time, and harvesting. In addition, to ensure and improve the communication and usability of the provided information, a call centre called Helpline was developed. The messaging service and call centres function in 12 different local languages and English (Schalkwyk, Young & Verhulst, 2017).

5.1.3 Case Study 2: Effects of PICSA on Smallholder farmers in Northern Ghana

Participatory Integrated Climate Services for Agriculture (PICSA) is an approach used by climate services and agricultural extensions which researchers at the University of Reading developed. PICSA works by combining historical climate data and forecasts with farmers' knowledge of what works. It then uses a participatory planning approach to help them make sound decisions about their agricultural practices (Clarkson, Dorward, Osbahr, Torgbor, & Kankam-Boadu, 2019; The University of Reading, n.d). PICSA is an approach that has so far been tested in 20 countries and has benefited tens of thousands of smallholder farmers' households. This includes over 75,000 households in Rwanda and 5000 families in Northern Ghana (Clarkson et al., 2019). PICSA is implemented in countries through close collaboration with trained staff or volunteers and farmers using historical climate data and forecasts. These trained staff or volunteers work with farmers to explore practical options that help them to address agricultural challenges that impede farmers from maximizing their production. This is done using participatory decision-making tools to evaluate and plan options that apply to the individual contexts of farms.

PICSA is founded on two primary principles. The first is based on farmers making their own decisions, while the second is the options by the context in which those decisions are made. PICSA uses the 'farmer decides' principle by emphasizing the importance of providing farmers with the suitable materials they need and leaving them to make decisions independently. Letting farmers make their own decisions is important because the farmer and their households sometimes take favourable and unfavourable decisions and are therefore in the best position to make decisions with their detailed knowledge of their farming methods and environment. Agricultural Innovation Systems (AIS) (Leeuwis, 2004; Klerkx et al., 2012) strongly supports the first of the two core principles of PICSA. It recognizes that multiple actors play a role in providing information and services to help farmers in their decision making whilst emphasizing that those decisions and the rationale behind them must come from the farmers themselves (Clarkson et al., 2019).

The PICSA approach was implemented through a series of training sessions with groups of farmers. Usually, each group has 3-4 sessions. Intermediaries were encouraged to work with the already established farmer groups instead of setting up new groups for training. These sessions enabled the trained intermediaries to work with farmers to complete the twelve PICSA steps (see Dorward, Clarkson & Stern, 2015). Each of the 12 PICSA steps has a set of well-crafted activities or tools that enable farmers to consider three things; firstly, farmers' context, secondly, their local climate and finally, their available options (Dorward, Clarkson & Stern, 2015). Ahead of implementing PICSA in northern Ghana, a scoping visit was done to introduce PICSA to potential stakeholders and information on the agricultural systems was gathered. Specific parts of the approach were then applied to local conditions to assess the availability and the quality of the historical data on rainfall stations. Before implementing PICSA in northern Ghana, the visit that took place was spearheaded by the Ghana Meteorological Agency (GMet), who visited stations to rescue and check records of climate data that were not in their database. Upon the successful completion of the scoping visit, a total of 42 agricultural field officers were trained. Some of these trained officers hailed from Mali and Burkina Faso. From Ghana alone, there were 28 agricultural field officers.

A random survey on selected farmers and detailed case studies in Northern Ghana to examine the impact of PICSA on farmers' decision-making, livelihoods, and innovative attitudes showed that 97% of farmers who participated in the study had changed their farming practices (Clarkson, Dorward, Osbahr, Torgbor, & Kankam-Boadu, 2019). These reported changes include starting new businesses and various management practices. In addition, farmers described overwhelming positive effects on their income, food security, well-being, and confidence in addressing climate change and variability. The case study interviews with farmers explained the motive for their shifts. It explained how farmers actively sought and obtained farming resources and technical information. Also, innovation processes observed show a significant contrast to those associated with linear technology transfer models. The quantitative survey conducted in Northern Ghana involved a sample size of 416 farmers (n=416). The farmers' case studies consisted of a sample of 18 (n=18). The survey and case study results clarified that both men and women farmers found the PICSA approach valuable and usable. In addition to the changes that farmers have reported, PICSA has enabled farmers to mitigate risks and capitalize on opportunities (Clarkson et al., 2019).

The results obtained from the investigation of the influence of PICSA on smallholder farmers in Northern Ghana shows it as a practical approach and can be implemented on a large scale; however, it is not without challenges. There are also essential elements that need to be looked at. First, considerable preparation is required to identify and work with crucial stakeholders and capacity building before and during the PICSA training with extension services. Second, before training extension works, capacity building is needed within National Meteorological Services (MIS) to prepare for climate products and locally specific agriculture and livelihood information. This process should be followed up with a logistical arrangement for the training and the follow-up implementation of structures and support. Third, long term sustainable capacity building requires the involvement of national governments and NGOs and the inclusion of this approach in their national policies and plans.

5.1.4 Case study of ICTs use on Climate Data outside Ghana

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) implemented a project in Senegal where they coordinated with the national meteorological agency and other stakeholders, including farmers themselves, to understand the benefits of using ICTs in agriculture. Findings from this study indicate the benefits of ICTs in agriculture at different levels. These contexts are:

1. More extreme weather events and climate shocks improved the capability of early warning systems, and this provided vital opportunities to cut down the erosion progress
2. The project allowed farmers to make their farm management decisions on tailored and accurate/reliable climate information throughout the farming cycle
3. It aided farmers in reducing climate risks and avoiding regular food and income insecurity
4. The results also showed that seasonal rainfall was downscaled. Long-term weather forecasts reached about seven million people in Senegal. This broad reach of weather forecasts is helping smallholder farmers to make well-grounded informed decisions about agriculture within a changing climate
5. Farmers were able to improve their adaptive capacity and farm productivity
6. Furthermore, an institutional, behavioural change was observed in the agricultural ministry of Senegal, which considered CIS as a vital source of reference to their annual agriculture action plan (Westermann, Thorton & Forch, 2015).

5.2.Findings from Interviews and Systematic Review

Findings from the six (6) interviews and a systematic review of a pool of eighty-eight (88) articles are summarized in the table below. The table was formulated after successfully coding the interview transcripts of the participants and that of the findings of the systematic review. First, the two summaries are organized into suitable themes and sub-categories to facilitate the conceptualization stage. Next, similar themes were merged into one unique theme, while duplicated pieces and responses were dropped. This step was then followed by the conceptualization process, where the summaries were presented logically. The table below summed up the main findings. In the table below, a systematic presentation of the results follows. Table 5 presents the summary of the interviews after the coding process.

THEMES	SUMMARY OF SYSTEMATIC REVIEW AND INTERVIEWS
The Interplay between Climate-Smart Agriculture (CSA) and Climate Services: How can farmers benefit from them?	● It is in recognition of three different goals of agriculture in the face of climate change; to ensure productivity and profitability, resilience in the face of climate risks and climatic climate stresses ● defining a new way to have smart-farming ● is equivalent to adaptation, climate change, adaptation, and then mitigation, and is seeking to reduce the contribution of agriculture to global warming, greenhouse gas burden ● making agriculture sensitive and innovative ● new ways of doing mix cropping to conserve the soil, increase productivity ● it is a new business model in farming ● climate services have four main pillars: generation, translation, transfer of communication, use ● to develop workshops and to communicate seasonal forecasts to farmers and tested it ● training agricultural extension workers and NGOs ● using PICSA approach to train and plan with farmers to understand forecasts ● helping farmers to decide instead of advising them ● to improve specific decision makings ● supporting local farmers to determine dry spells, amount of rainfall, planting periods, types of fertilizer to use, windy conditions, soil moisture ● helping farmers to not only know the forecast but to know what

	happened in the past ● tests were done in Kenya, Senegal, Tanzania, Rwanda and Ghana, and farmers were able to make decisions based on hypothetical forecasts
Collecting, Analysing, and Communicating Climate Information using ICTs and BDA	● climate data is collected at meteorological stations; from national meteorological services across Africa and the world ● data is also generated from ICTs such as mobile phones, meteorological stations, satellites, etc. ● the use of an automatic weather station that registers the parameters automatically ● from global space centres like NASA, ESA ● the use of satellite technology such as Meteosat ● combining data from satellite and meteorological stations data ● private sector companies and government make use of the data ● accessibility to the collected data should be expanded ● data should be metamorphosed to encourage big data processing ● farmers should be involved in the process ● data should be well translated for informed decision making ● processing climate data depends on what you want to have ● tools such as Excel, CDT, CLI software, Climate data tool, and other complex software are used ● some use a database management system for analysis ● ICTs and BDA help in providing localized information based on analyzing historical meteorological records to downscale and interpret forecasts of different lead times ● helping to develop very advanced suites of freely available online climate information ● weather information can be communicated using ICT such as mobile phones and mass media effectively; information needs

	to people very quickly at a shorter lead time ● smartphones or videos can help group processes; human interaction has proven to be much more effective and is much better suited for information at that climate timescale. ● face to face processes is being used to lead farmers to understand their local climate ● communication between sectoral and climate scientists ● government's direct interaction and communication with farmers ● information from national meteorological services ● farmers Helpline for communicating weather and crop information to farmers
Key Actors/Stakeholders	● national meteorological centres world Meteorological Organization (WMO) of the un ● agricultural ministries; national frameworks for climate services ● research institutes such as the IRI (International Research Institute for Climate and Society) ● farmers, agribusinesses, extension workers ● national agricultural research and extension ● NGOs such as FAO, UNDP, FAO, ESA, WMO, TIAS Ghana, footprint bridge are leading the force in the Agric space ● universities that take part in agricultural development programs ● government and the ministry of agriculture

Problems and Challenges of Using ICTs and BDA on climate data	● there are a lot of gaps in the historical record ● one can invest in new weather stations but can't recreate climate data history to be able to understand how the climate behaves, the variability and trends and seasonal cycles ● data transparency, ownership, and quality issues ● National Meteorological Services are very protective of their data; restrictions to access and use historical data ● Organizations that provide high-quality data often convince donors to fund them ● NGOs may provide local data to farmers in a short time, but this may undermine the national meteorological stations ● private companies with inferior products competing with national meteorological services lead to wrong forecasts ● private sectors are good at providing information to farmers with access to ICTs but poor at delivering accurate climate data or forecasts ● Meteorological stations use data to generate revenue and thus withhold it from the public ● lack of enough resources to generate income, data is used instead ● data owned by NGOs such as FAO is easily and freely accessible ● Coercing farmers to purchase these technologies in exchange for fertilizer or other benefits ● using technologies as a political tool to grip on to power by manipulating farmers ● engagement with technology providers or manufacturers to supply or make technologies that smallholder farmers need ● data gaps can be filled by merging available quality-controlled meteorological station data with satellite remote sensing, proxy data for rainfall and climate model re-analysis

	• Network connectivity issues for rural farmers
The Role of the Government, Extension Services, and NGOs	• bringing in digital technologies and digital innovations to support existing institutional services, to supplement and not replace agriculture extension • make digital tools available to farmers • develop intergovernmental frameworks for delivering climate information • develop climate and technology policies • the government of Ghana is calling for the digitalization of its economy • helping to ensure tremendous access to network connectivity • providing mobile money and banking to rural farmers • refinement on subsidiary, people on subsidiary on mechanization to use • introduction of new government policies such as planting for food for rural farmers • government policies sometimes favour politicians, but some of the policies put in place are working • the government is helping to uplift the rural livelihoods and incentivize technologies for smallholder farmers

ICTs and BDA: Benefiting Smallholder farmers from Climate Data in CSA	• farmers can benefit from climate information by interacting with farmers daily to make them understand forecasts; interacting and bringing new information to them • make them know simple weekly forecasts as opposed to seasonal forecasts, which are more complex • climate data becomes a foundation for developing a wide range of products, historical analyses, analyzing rainfall and temperature in ways that are important for agricultural decision-making can impact crops and livestock productivity • invest in the communication and then building the capacity on the demand side of climate services • use a voice rather than a text-based medium in their local language • present weather information to farmers in a careful, systematic way that starts with kind of their memory, their understanding and walks them through one step at a time • because their livelihoods are stochastic, their income is probabilistic; their survival is risky. so, they understand the risk • an impact evaluation study on a case in Rwanda for farmers' use of climate services for insurance and social protection yielded the following: • farmers were grouped into radio listening clubs and met every week to listen to forecasts • 113000 farmers who participated well were able to scale up their production • 4% of the Rwandan population were reached • the average value of their crop production increased by 24% • net income from crops increases by an average of 30% • translates to a minimum of like $3.87 million increase in farmer income from crops • 4.5 million USD added to the agricultural economy through

	increased production (End of Rwandan case) ● in Ghana, Esoko had a 10% increase in income ● 70% of the farmers in Ghana benefit in one way or the other ● more than 45% increase in terms of sustainability models ● impact on knowledge and skill-building ● newly added knowledge, skill, and information for farmers ● creation of new business models and new job opportunities for smallholder farmers

Table 5: Summary of findings from interviews and systematic review

5.2.1. How can farmers benefit from CSA and CIS?

Climate Services (CS) and CSA are concepts within smart-farming that closely work together and are often misunderstood to be the same. To understand these two concepts and expound on ICTs and BDA's role in these farming approaches, the interview participants were asked to define and give their understanding of the two. The explanations provided by the participants are in line with what the body of literature has shown. According to the participants, CSA is a new farming technique that aims to have a "new smart-farming approach." According to interview participant 1, "it is an approach that is in recognition of three different goals of agriculture, and these three different pillars are the foundations on which CSA is built." In the face of climate variability, climate change, and the increasing food demand of the rising global population, the interview participants all buttressed on the importance of CSA (Huyer & Nyasimi, 2017). They emphasized how the three main building blocks could be adopted in developing countries to benefit the smallholder farming population. CSA aims to increase productivity and profitability, maximize resilience in crops and animals, change farmers' farming habits to climate risks and climatic stressors, and reduce or eliminate greenhouse gas emissions (Hansen et al., 2019). The definition offered by interview participant 2 was similar to that of participant 1. Participant 2 had, however, explained CSA in light of adaptation and mitigation to climate change in ways that seek to reduce the contribution of agriculture to global warming or greenhouse gas burden. "It is a way of making agriculture climate-sensitive and innovative." Approaches in CSA are helping farmers, small-scale farmers from developing countries, in particular, to strengthen their efforts and capacity to meet the three main outlined pillars. When interview participant 3 was quizzed on how smallholder farmers in developing countries could meet these pillars, the response given was that CSA brings new farming approaches to farmers that do not involve the use of more land to improve productivity. Instead, it seeks relatively new ways of practising novel farming methods such as mix cropping and mix-planting to "conserve the soil, and increase productivity." Many researchers understand CSA as a new business model in farming that encourages close collaboration and participation from all players to ensure benefits in productivity, income, improved livelihoods, and resilience to climate change variabilities (Lipper et al., 2015). All participants acknowledged that CSA might have many criticisms and challenges; however, it does not limit its potential in meeting the UN's SDGs of zero hunger, no poverty, and climate action. They reasoned that introducing new technologies in agriculture and using them to their fullest potential can take time and might fail to materialize in specific settings or environments. Nonetheless, they maintain that since its widespread adoption and use in both developed and developing countries, CSA has recorded significant success stories that could encourage governments to mainstream CS and CSA in their national policies (FAO, 2018). It was further noted in the systematic review and interviews that encouraging and helping farmers to adopt new methods of farming in the age of technologies will not only increase their farm productivity but will also enlighten them and equip them with new skills and tools to devise methods that work for them in their specific contexts of resources.

Questions regarding the interrelationship between CSA and CS were put forward before a few participants worked in those areas. The findings from the literature review and their explanations are closely matched. If any variations exist, these are just in the wording and contextualization of the terms and their applications. What was clear from them is that CS could be considered a subset of CSA while both CSA and CS could be classed under smart-farming. Interviewees from Ghana and those not from Ghana but have worked with smallholder farmers and on projects targeting smallholder farmers in Ghana have provided various examples of these two farming approaches juxtaposed and used concurrently. The case study of northern Ghana was frequently cited as an example success story. The PICSA approach was used to benefit smallholder farmers through climate information and weather forecasting. They explained how ICTs were used to disseminate weather information to farmers to help them make their farming decisions. The PICSA approach, as described by two of the interviewees, is an excellent example of how ICTs and BDA are used in agriculture to benefit smallholder farmers. Although to earn maximum benefits from new farming methods, they argue that there should be face to face interaction with farmers through active participation on the field and through workshops to educate farmers to know how and when to use specific tools and decisions in their day-to-day farming activities (Richards et al., 2016). Examples from Kenya, Ethiopia, Senegal and Rwanda, where PICSA was tested on farmers, have been cited as examples to strengthen their argument supporting the adoption and use of ICTs and other tools in agriculture. The interviewees stressed the importance of climate data and weather forecasting for farmers in agriculture.

Unlike CSA, participants 1 and 3 gave their take on CS as a practice constructed around four main pillars and only focuses on analyzing climate data using satellites, meteorological stations, and other data collection and analytics technologies. The four pillars of CS are generation, translation, transfer of communication, and the use of information. Participants 1 and 3 explained these four pillars in detail in light of climate data. Generation involves all the processes in collecting and gathering climate data from various sources, including satellites, local, national, regional, and international meteorological stations (Roudier et al., 2014). Climate data is gathered from these different sources to analyze it to generate insights. After collecting climate data using various technologies, the next stage is the translation phase. The data is analyzed using advanced BDA analytics tools. Participant 1 explained what constitutes big data. It is the combination of massive climate data from meteorological stations combined with satellite many years of data that has been collected by satellites. These large datasets are difficult to analyze without using advanced and intelligent analytic technologies. When asked what kind of technologies are used to do the analysis, they mentioned many data tools such as Excel, CLI and machine learning methods. They maintained no specific analysis mechanism, and each organization or meteorological station may have its analytic tools. The next phase that comes after climate data translation is called the 'transfer of communication'. This phase was described as the most crucial phase since it disseminated the insights or information they obtained from their analysis to farmers. In developing countries where most farmers are illiterate, the two participants iterated the importance of carefully crafting or tailoring the climate information to the needs and understanding of the farmers because lousy communication can lead to wrong farming decisions. Information is usually communicated using local radios, TVs, SMS or voice notes and so forth. The final pillar of CS is the use or the application of the transmitted information. It is the responsibility of the agricultural ministries, extension workers, farmers, and trainers to train farmers in using and applying the climate information and weather forecasts communicated to them to make farming decisions such as time of planting and harvesting, type of crops to grow.

The participants were asked to explain how CS is helping local farmers while complementing the pillars of CSA. According to them, CS helps to develop workshops for trainers and farmers where they teach them how to interpret seasonal forecasts. In addition, they train agricultural extension workers and NGOs. They play an active role in collaborating with farmers and agricultural ministries to improve the national agricultural development plans. The training involves using the PICSA approach to help farmers decide instead of advising them and improving specific decision-making. The interview participants argue for the importance of the pieces of training farmers and extension workers receive. Based on their explanation, these pieces of training support local farmers to determine dry spells, the amount of rainfall to expect, planting periods, types of fertilizer to use, windy conditions, soil moisture.

Moreover, the pieces of training help smallholder farmers know the forecasts and know what climatic variabilities had happened in the past (Muema et al., 2018). From the literature, evidence showed that tests to determine the impact of CS and CSA on smallholder farmers were done in Kenya, Senegal, Tanzania, Rwanda, and Ghana. These tests showed that farmers could make decisions based on hypothetical forecasts (Clarkson, Dorward, Osbahr, Torgbor, & Kankam-Boadu, 2019).

5.2.2 Collecting and Processing Climate Information using ICTs and BDA

How is climate data collected, analyzed and transmitted to farmers using ICTs and BDA? According to the systematic review and participants' responses, climate data is collected at meteorological stations from national meteorological services across Africa, from global space centres like (ESA, satellite technology such as Meteosat, and ICTs such as mobile phones. Historical gaps in the data from national meteorological stations have been widely acknowledged in the literature and interviews (Delgado et al., 2019). Evidence shows that data gaps often lead to flawed analysis, leading to wrong insights (Nanni, Thanos, Giannotti, & Rauber, 2014). To cover the historical climate data gaps from meteorological stations, data from local stations is often combined with satellite data and data from international stations. Merging data from satellites, meteorological stations, and other sources typically yield more accurate insights, leading to reliable climate and weather forecasts. When the participants were asked how big data processing can be encouraged in climate data collection and processing using ICTs and BDA, participants 5 and 6 suggested metamorphosing climate data. They believed that private sector companies and governments play a role in data metamorphosis for easy accessibility and expansion in scope. Literature shows that collecting data using automated tools such as satellites, ICTs, and meteorological stations is not enough to provide insights to farmers that could benefit them by improving their decision-making. It has been shown that involving farmers in the data collection, processing, and communication cycle through participatory processes would lead to wide-scale adoption and intelligent use of the forecasts that would be communicated. Figure G below shows possible data limitations that may arise during climate data collection and analysis.

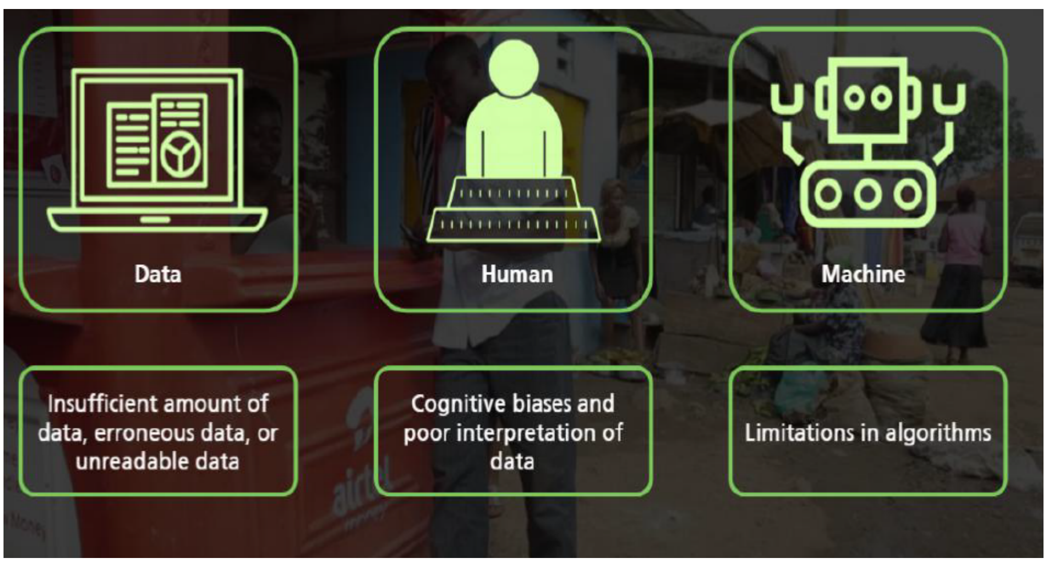


Figure G. Limitations in data collection and analysis (Source Popa, 2011)

Since there is no data processing standard in agriculture, participant 4 argued that processing climate data varies and largely depends on what you want to have. The participant maintained that different tools such as Excel, Catalog Data Technologist (CDT) tool, and other complex software are used to analyze climate data. In addition, some climate data collection organizations use a database management system for analysis. How do ICTs and BDA help farmers in their farming decision making using climate data? The participants have all given similar responses to this question. It was noted from their responses that ICTs and BDA help farmers have access to localized weather information based on the analysis of historical meteorological records to downscale and interpret forecasts of different lead times. ICTs and BDA help in the development of advanced suites of freely available online climate information.

Furthermore, weather information can be communicated using ICTs such as mobile phones and mass media because "information needs to reach smallholder farmers very quickly at a shorter lead time (Jiménez et al., 2019)." Participants 4 and 3 explained the role of smartphone and video services in the weather forecasts communication process. They reasoned that these technologies could help with group processes. E.g. Human interaction has proven to be much more effective. It is much better suited for information at the climate timescale. Face to face processes are also being used to lead farmers to understand the local climate. Other uses or roles played by ICTs have been linked to their mediating effect, particularly the mediation they play between sectoral and climate scientists, governments' interaction and communication with farmers. In Ghana, telephone centres such as 'farmers Helpline' help communicate weather and crop information to farmers. Information from national meteorological services is often provided by agents working at the Helpline. Farmers make calls and send their inquiries there. The responsible personnel communicate information to farmers based on their individual needs.

5.2.3 Role of Key Actors/Stakeholders

Understanding the actors or players in climate data generation and analysis using ICTs and BDA within CSA is quite essential. The participants have cited the names of various actors that partake in the climate data ecosystem. The multiple actors or players mentioned by the interview participants are more or less the same as those shown in the literature review. According to the participants, the role of actors is to ensure there is close collaboration and partnership between them throughout the climate data cycle. They posit that each of the actors has a role to play and should also work towards fulfilling the main objectives and goals of CSA. The different actors/stakeholders that were cited are given below:

1. National Meteorological Centres
2. The World Meteorological Organization

3. National frameworks for climate services
4. Agricultural Ministries
5. National and international research institutes
6. Farmers and agribusinesses
7. Extension workers
8. Non-Governmental Organizations (NGOs) such as FAO, The United Nations Development Program, The World Bank, ESA
9. Universities that take part in research and development programs

The respondents affirmed that building a solid collaboration and relationship between these different actors is needed to ensure that smallholder farmers receive the maximum benefit from the gains obtained due to using ICTs and BDA on climate data within CSA (Branca et al., 2012). These actors can bring in digital technologies and digital innovations in agriculture to support the existing institutional services and supplement agricultural extension's role instead of completely replacing it. Some respondents suggested that certain actors such as governments, agricultural ministries, and NGOs can make digital tools available to farmers. As a result, intergovernmental frameworks for delivering climate information can be developed, and new climate-smart technologies and policies can be implemented (United Nations, 2019a). The responses from the participants showed that the government of Ghana is calling for the digitalization of her economy to help ensure farmers have access to markets, network connectivity, farming tools, and other resources. Part of the digitization process involved providing mobile money and mobile banking to rural farmers through ICTs such as mobile phones (FAO, 2019). One of the interviewees explained that the Ghanaian government is currently refining subsidiaries for farmers, such as subsidiaries, on-farm mechanization. The government is also rolling out new government policies such as planting for food for rural farmers programs. Most of the participants argued on the usefulness of government policies in using ICTs and BDA tools to benefit smallholder farmers in agriculture. They explained that though most government policies sometimes favour industrial or large-scale farmers, some policies work. The government of Ghana is currently helping to uplift the rural livelihoods and incentivize technologies for smallholder farmers.

5.2.4 Problems and Challenges of Using ICTs and BDA on climate data

Climate data obtained from meteorological stations, satellites, and from other sources using ICTs may be acted upon using BDA approaches; however, the accuracy and usefulness of the generated climate insights and weather forecasts may be questioned if the data quality is poor (Amarnath et al., 2018). Therefore, it was essential to understand the current challenges of responsible stakeholders involved in climate data collection and analysis. Questions regarding data quality and data ownership issues were raised during the interviews. According to the participants, the major problems lie in data quality, data ownership and accessibility.

Having large enough climate data ready for analysis may offer some convenience; however, participant 3 said, "the quality of data is what matters most." Three of the respondents raise the issue of having gaps in the historical climate data record and see it as a significant challenge when dealing with climate data analysis. They see this as a substantial challenge because even though one can invest in new weather stations, it is impossible to recreate climate data history to understand how the climate behaves, the variability trends, and the seasonal cycle. Advancing the gaps in climate data records, participant 3 recalled a moment when wrong and inaccurate weather forecasts were communicated to farmers during a fieldwork trial in Ghana, leading to poor decisions. During that trial, the people working with farmers came up with novel ways to overcome gaps in climate data records. They did this using a combination of satellite data and data from local stations and subsequently performing what was called a 're-analysis.' From the literature, it was found that data gaps can be filled by merging available quality-controlled meteorological station data with satellite remote sensing data, proxy data for rainfall, and climate model re-analysis.

Another critical data issue found within the literature and raised by the participant is data transparency, data ownership, and external or political influence. A significant issue that needs to be overcome by the respondents is that restrictions to access and use historical climate data should be removed, and National Meteorological Services (NMS) should not be overprotective of their data. In Ghana and most countries, data from local or national stations is quite challenging to access for acting upon it by responsible actors to generate insights that can be communicated to smallholder farmers on time. Instead of making data freely available to the public, meteorological stations use their data as a means to generate revenue. Two of the interviewees rationalized that when necessary historical climate data is withheld from the use by the public, private companies, and profit-seeking data companies may capitalize to market their weather forecasts to farmers in a short time so that farmers turn to them for help in exchange for a small fee or token. These private companies and organizations might quickly provide climate data to local farmers, but this may undermine the work of the NMS. They are because private-sector data companies are good at providing information to farmers who have access to ICTs. Still, at the same time, these companies are poor at delivering accurate climate insights or forecasts. The respondents further argued that when meteorological stations use data to generate revenue, organizations that provide high-quality data will convince donors to fund them to replace meteorological stations, leading to inaccurate forecasts for farmers. NMS using data to generate revenue was attributed to the lack of enough resources to generate income. Thus, data is used as a business model instead.

Several other challenges have been raised during the interviews, and evidence from the systematic review also confirmed the respondents' responses. These points are:

1. Governments, NGOs, ATPs, and Private sector companies forcing farmers to purchase climate data communication technologies in exchange for fertilizer and other benefits.
2. Using these data technologies as a political tool to manipulate farmers.
3. Government's possible engagement with climate data providers and ATPs to supply or make technologies that smallholder farmers that do not need
4. Network connectivity issues that prevent farmers from actively taking part in the climate data cycle.
5. Lack of proper understanding as to where the data flows and who owns it.

5.2.5 ICTs and BDA: Benefiting Smallholder farmers from Climate Data in CSA

The introduction of new farming tools and techniques in the agricultural sector is currently present in many developing countries in Africa. Nevertheless, the real question is, how are these new farming techniques benefiting smallholder farmers who are the leading food and income providers for most of the population of Ghana and Africa as a whole? This question was well-received by all the interview participants. Their responses cited examples from Ghana and a few African countries where the PICSA approach was used and the success rate it has registered. Others pointed out current practices in CSA and CS where ICTs and BDA play significant roles in improving farmers' productivity. However, despite the strong approval of the interviewees for the use of smart-farming tools and the introduction of new farming approaches, they acknowledge the current challenges these farming techniques and tools face and how they could be tackled.

The responses from the interviews and the systematic review showed that direct interaction with farmers using approaches such as PICSA could greatly benefit farmers to have access to climate information, understand forecasts, and improve their decision-making. Using methods such as PICSA helps farmers know and interpret simple weekly forecasts because seasonal forecasts are complex. When a farmer understands seasonal forecasts, poor farming decisions are often avoided. This increases the on and off-farm productivity of the farmer (Branca et al., 2012). Findings from the literature asserted that climate data had become a foundation for developing a wide range of products and services such as historical analyses, analyzing rainfall and temperature. These products and services are essential for agricultural decision-making and can impact crops and livestock production. Interview participants 3 and 6 suggested that for farmers to earn maximum benefit from ICTs and BDA, governments and NGOs, including other relevant stakeholders, should invest more inaccurate climate information and forecasts and focus on building the capacity on the demand side of CS (FAO, 2019).

When the participants were quizzed to explain how whether the information is presented to farmers in a way that they can understand, three of them elucidated on this, arguing that whether information should be presented to farmers in a careful, systematic way that starts with their memory, their understanding and then walking them through the interpretation process one step at a time. The understanding and interpretation process can be aided by using a voice message rather than a text-based medium in their local language. When participant 1 was asked whether illiterate farmers can follow the weather information understanding and interpretation process, the response given is that because farmers' livelihoods are stochastic, their income is probabilistic. Their survival is risky, so they understand risks, are aware of risks and try harder to mitigate these risks by patiently working with extension workers and training officers to understand weather information. Results from a few case studies similar to the case study in northern Ghana were given by a few of the participants to solidify their arguments on the use of ICTs and new farming approaches to maximize agricultural productivity. An impact evaluation study conducted in Rwanda to evaluate farmers' use of CS to maximize farm productivity for insurance and social protection was cited. In that study, about 113,000 Rwandan farmers took part. Farmers were grouped into radio listening clubs and met every week to listen to forecasts. All the farmers who participated reported that they were able to scale up their production. In that study, 4% of the Rwandan farmers were reached. The average of their crop production increased by 24%, while the net income from crops increased by an average of 30%. The results translate to a minimum of $3.87 million increase in farmers' income from crops, and $4.5 million was added to the agricultural economy through increased production. A similar study was replicated in Ghana using the PICSA approach, as reported in the case study findings. One of the respondents also uses the case of Esoko as an example showing the success of using climate data, ICTs and BDA to make weather forecasts to farmers. In one case study, Esoko had a 10% increase in farmers' income and 70% of farmers in Ghana benefit in one way or the other from climate information. Reports show that there is more than a 45% increase in terms of sustainability models. Training with farmers also impacted their knowledge and skill-building and created new business models and new job opportunities for smallholder farmers.

6. Discussion

As previously mentioned, the global population is expected to reach approximately 9 billion by 2050 (United Nations, 2018). The majority of this growth will be seen in poorer countries, such as low-income countries in sub-Saharan Africa. Thus, to meet the food demand of the global population, farmers or producers must be able to increase productivity both in livestock and crop intensity and diversify their portfolio of economic activities on or off the farm. However, farmers are only too aware of the risks and challenges posed by a changing climate, knowledge and skilled barriers, limited resources, and the pressure of a growing population. As a result, multiple approaches such as the use of ICTs, BDA, CIS, and CSA have been adopted to support their efforts, including developing and using crop and livestock production innovations, generating and sharing knowledge, and developing better crop varieties and animal breeds. Farming practices that use past climate data to forecast weather and climate events for farmers to base their farming decisions are widely used in many African countries. However, these practices are novel, and they often involve the active or passive participation of smallholder farmers. Hence, this study explores how ICTs and BDA can be used in CSA to generate and analyze climate data and the circumstances under which they can increase productivity for smallholder farmers. Despite the wide availability of ICTs and data analytic technologies, several factors influence their effectiveness in enabling smallholder farmers to benefit from their potential. Having analyzed the results of this study, a discussion on the conditions under which smallholder farmers can benefit from these technologies to maximize productivity is given in this section. This discussion is followed by recommendations that stakeholders can adopt to help smallholder farmers in developing countries adapt to CSA and CIS practices using the powers of ICTs and BDA.

6.1 Increasing Productivity for smallholder farmers using ICTs and BDA

On a bright note, almost all of the paths that help offset current trends and increase agricultural productivity growth can benefit from changes in the ways climate data is collected, generated, analyzed, and visualized. Recent advancements in ICTs have enabled individuals to tap their intellect to gather, explore, and share data more effectively and visualize and understand the implications of the generated climate information on agriculture productivity for smallholder farmers (Collier & Dercon, 2014). The ability to capture and analyze climate data has been introduced in CSA approaches under the banner of CIS, and these methods have been growing exponentially with the global spread of ICTs. When data is collected *en masse* using ICT capabilities, it is referred to as big data. Climate data collection tools such as satellites and other ICT powered machines combined with advanced BDA techniques are providing farmers with a more accurate understanding of the existing climate conditions and also help in generating better predictions of future conditions in the form of climate forecasts, thereby enabling them to make more informed, and real-time decision making (Sultan et al., 2020). The involvement of many actors in such farming practices means that there are different benefits to different stakeholders. Findings from this study show that many of the stakeholders involved in the use of ICTs to benefit smallholder farmers may be looking for ways to exploit the weaknesses of these poor farmers so that they can market their technologies and partially or wholly transfer the responsibility of mitigating climate change to them (Muema et al., 2018). To increase the productivity of smallholder farmers, concerted efforts need to be made by all other actors to focus on implementing policies and practices tailored toward uplifting their livelihoods instead of playing the game of politics or power relations and technological merchandising. Based on the findings, it is worth mentioning that maximizing the agricultural productivity of small-scale farmers through ICTs and BDA in CSA largely depends on five primary factors. These are:

1. Quality of the climate data and accuracy of weather forecasts
2. Knowledge and skills of small-scale farmers
3. Effective communication
4. Ensuring effective collaboration among actors as proposed by the AIS framework
5. Developing national agricultural policies using the NIS perspective

When climate data is collected from meteorological stations, satellites, and mobile phones in developing countries, ICTs and BDA tools help analyze it and communicate the generated insights to small-scale farmers. As it has been noted, the problem of historical climate data gaps often emerges as a challenge because these gaps may lead to misleading or inaccurate insights. Therefore, responsible actors tasked with collecting climate information should first ensure that data gaps are adequately filled by merging data from satellites with local and national meteorological stations. Improving data quality before performing any analytic procedures will significantly reduce bias and the potential for errors (Dinku et al., 2011). When flawed quality data is acted upon, the resulting consequence is wrong decisions by farmers because most smallholder farmers in Ghana and other African countries are primarily illiterate who cannot distinguish between poor and good quality forecasts. Therefore, minimizing climate data inconsistencies should be enforced from the onset of the data processing cycle, right before any analysis is done.

ICTs are both used to collect, analyze and communicate climate information. However, when the data is transmitted to farmers, the way they understand the communicated forecasts has a heavy influence on their farming decisions, thus determining their farm productivity (Hansen et al., 2019). It is important to stress that for ICTs and BDA to be effectively used in CSA as tools to act on climate data to generate forecasts based on historical data, the knowledge-based repertoire and the skillset of smallholder farming in understanding and applying this information should be improved. Communicating complicated information to farmers is not enough if the farmer cannot comprehend what is being communicated. Actors such as research agents or institutes, agricultural ministries, governments, universities, NGOs, donors, etc., need to work in unison to generate and share knowledge amongst themselves and farmers through workshops, seminars, and conferences. Knowledge generation and exchange regarding the use of ICTs, BDA, CSA and climate information may help break the issue of information asymmetry and can encourage active participation of smallholder farmers in all critical activities. NIS and AIS advocate for the collaboration of all the actors in the innovation process (Klerkx, 2015). Smallholder farmers are an integral component of the climate data generation and analysis process. They should be the primary beneficiaries of the outcome of innovative agricultural approaches. This study shows that direct interaction with smallholder farmers is a very effective means of working with them and understanding probabilities and weather forecasts through charts, posters, banners, SMS, television, local radio, and voice messages. Governments' involvement can help direct interaction by implementing national policies that mainstream ICTs and BDA on climate data.

6.2 Channel the Gains from ICTs and BDA in CSA to Smallholder Farmers

The involvement of different players in the climate information ecosystems means other implications for various stakeholders. When the power of ICTs and BDA are employed on climate data, the vital thing to understand is how to effectively communicate the generated insights and channel the benefits to smallholder farmers. ICTs such as satellites, meteorological stations, sensors, and mobile phones contribute to big data sets used by a wide array of stakeholders (World Bank Group, 2017). For example, when hyper-localized weather data is being collected and processed, the various stakeholders may receive a wide margin. This study identified five main actors in agriculture: the farmer, ministry of agriculture, government agencies, donor agents, and private sector. In Ghana, rural farmers are often at a considerable disadvantage of not reaping the actual benefits or gains from climate data. Apart from farmers using the climate information for better planting decisions based on accurate weather forecasts, the ministry of agriculture should use the same climate data to give precise information to farmers about local weather patterns, disease and pest populations and then tailor this information to extension services (Bennet, 2015).

Additionally, government agencies should also use climate information to benefit the smallholder farmer by opening avenues to allocate resources to producers based on hyper-localized events. The government's agencies and agricultural ministries can help agricultural donors access data. Programs that are well attuned to local needs can be designed and developed to benefit the small-scale farmers in rural regions. In the past, private sector companies could not deliver certain services due to a lack of access to weather data. Their involvement in accessing and processing climate data can benefit farmers in many ways. For example, they can now deliver weather insurance programs to smallholder farmers and provide them with additional incentives that can help them improve their livelihoods and maximize crop production.

6.3 Identify ICT Drivers and Use ICTs as a Means to an Agricultural End

ICTs and other technologies should be considered a means and not an end to the development of agriculture. This is because the excitement generated by any new technology as it diffuses throughout developing countries typically masks their contributions to agriculture, making them poorly understood. While there is credible evidence showing the positive impact of these technologies on smallholder farmers, it is essential to ask how to make these innovations sustainable, replicable, and scalable for a more extensive and more diverse group of rural farmers in sub-Saharan Africa. Several pieces of evidence show the impact of using ICTs and BDA in CSA to benefit farmers in rural poverty reduction and explore opportunities for long-term and extensive efforts (FAO, 2018). Through the collaboration of actors, critical drivers of ICTs and BDA in CSA need to be identified. The key drivers that have been identified in the literature are summed up in figure F below.

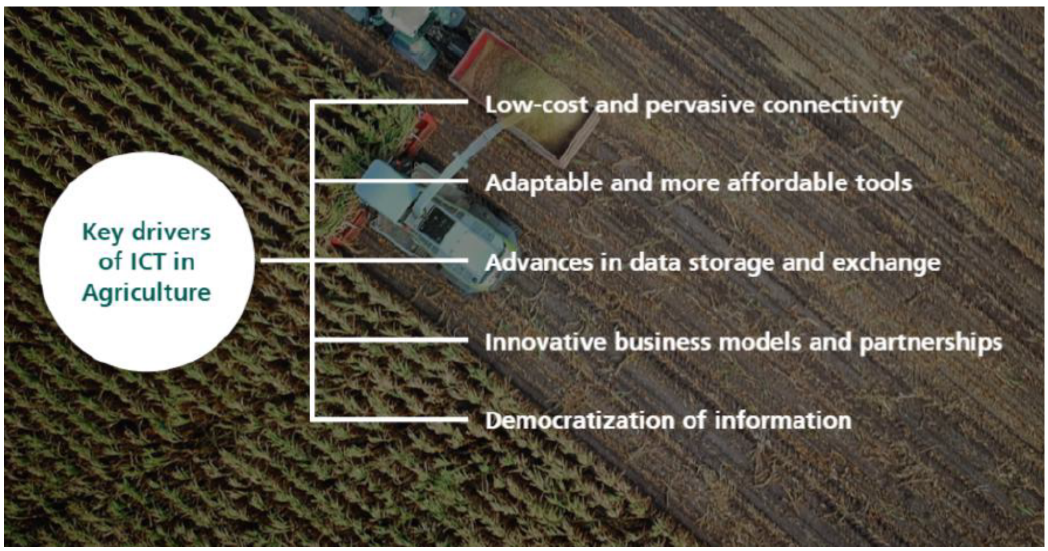


Figure F. Key ICT drivers in Agriculture (Source FAO, 2019, World Bank Group, 2017)

For smallholder farmers to improve their productivity, low-cost and pervasive connectivity should be provided to them to help them have access to real-time information. Generating climate data is one aspect, and communicating it to farmers is another significant aspect that is the most important. When farmers do not have access to connectivity, they may lose track of incoming weather information. Information may only arrive when it is not helpful. The pervasiveness of connectivity to mobile devices, the internet and other wireless devices can make ICTs and services more affordable in ways that also improve access to small-scale farmers. Mobile phones are one of the main vanguards of ICT use in the agricultural sector.

Furthermore, the proliferation of adaptable and more affordable technologies and devices (World Bank, 2018) can increase the relevance of ICTs and BDA to smallholder farmers in CSA. This is because innovation helps to steadily reduce the purchase of phones, specialized analytics software, laptops. Currently, agricultural innovation programs in developed countries have even become more adaptable and widely applicable to the needs of developing countries. Mobile-based applications are particularly becoming more suited for poor and isolated communities. Drawing on simple, affordable digital services such as SMS, voice message, service providers can offer real-time weather information to smallholder farmers (World Bank Group, 2017). For example, when geospatial information is combined with climate data, it can open many avenues for analyzing climate trends and selecting particular groups to test the potential of emerging technologies or farming methods.

The issue of gaps in historical data can hinder the accuracy of climate information which may subsequently lead to poor farming decisions by farmers. Government ministries and NGOs should upgrade data storage and exchange mechanisms to increase and access climate data remotely and share it can become manageable. Knowledge sharing and data exchange can create new opportunities to involve stakeholders in agricultural research (World Bank, 2007). Advances in data storage and sharing can also improve interaction and communication with smallholder farmers on a timely basis so that costs associated with data transmission charges can be avoided. The development and use of many ICTs and BDA tools originated from the public sector. However, they were quickly dominated by the private sector as soon as their profit potential became apparent. The public sector should use the powers of ICTs as a means of providing better public services that affect agriculture to rural farmers.

According to the findings, there is a massive barrier for responsible actors to access and use historical climate data. When the people concerned cannot access and use climate data to benefit farmers, farmers will make farming decisions based on conventional practices that may not be sustainable or productive. For ICTs and BDA to effectively act on climate data, there should be equal access to the historical climate data without any unnecessary restrictions (Thornton et al., 2018). Therefore, it is necessary to democratize climate information, including the open access movement and social media. Information asymmetries can be overcome when there is open-access online data. The value of climate data can exponentially increase as all actors will perform their analysis to benefit the relevant farmers. The democratization of information and science-knowledge-based policies facilitated by ICTs can contribute to agriculture and rural development in many ways. Large quantities of climate information held by meteorological stations, individuals, institutions, and satellites should become publicly visible and accessible through the open access movement (Dinku et al., 2011). When there is open-access software, grassroots communities and organizations can share knowledge. However, making climate data from national meteorological stations (NMS) freely available as a public good is challenging since it will require changes in data policies and potential adjustments to the ways public funds are allocated to NMS (Hansen et al., 2019).

6.4 Active Engagement Smallholder Farmers

Participatory communication processes provide a forum where farmers can co-learn and communicate with researchers and climate information providers on a pilot scale. Research pioneered by Hansen et al. (2019) showed that participatory communication processes are more effective at increasing the understanding and the willingness of farmers to act on complex climate information, as proven by controlled studies in Zimbabwe Burkina Faso. Such processes indicate the high rates of climate information use and positive evaluations of the PICSA process. Active participatory communications are effective because they help overcome the cognitive setbacks to processing and using uncertain and complicated information. Hence, a balanced and comfortable environment for co-production of climate information through ICTs and BDA. However, co-production is not a result that is assured based on dialogue; instead, there are obstacles on either the supply or the demand side that prevent co-production from impacting climate information (Hansen et al., 2019). Limited available evidence shows that through active participatory processes, farmers' understanding and use of climate information improves even though they do not reduce the gap between available information and farmers' needs.

NMS use different communication channels to transmit weather and climate information. These channels include broadcast media, mobile phones, and various face-face communication. Such communication channels are typically run through the help of agricultural extension services and other intermediaries. These communication channels play a crucial role in transmitting weather forecasts to smallholder farmers. Face-to-face participatory processes are generally effective for initial learning and seasonal planning. They also provide an opportunity for feedback used to design effective services (Dinku et al., 2011). Radio and television are more suitable for building awareness and reinforcing concepts introduced through participatory processes. Mobile phones can be used to push location-centric weather data and alerts of extreme events as a voice message or SMS. They also provide specific information through call centres. The increasing rural mobile penetration is expanding possibilities for accessing climate information and advisory services to smallholder farmers, for developing training and reinforcing concepts through video services. The results suggest that ICTs and BDA aid in the generation of climate insights, and the delivery of climate services for farmers is best supported by a combination of participatory approaches that are innovative and scalable. Nonetheless, there is still a gap to understand how they can be best combined to meet context-specific needs.

6.5 Use Appropriate Technologies and Concentrate on Their Demand

The attractiveness of new ICTs or any digital technology can lead to a preference for the latest technologies at the expense of older ones. However, the most recent or most innovative technology is not always the most appropriate one. However, a clever mix of technologies such as mixing radio programs with a call-in service or SMS or voice facility for feedback can prove to be more cost-effective (World Bank Group, 2017). A well-thought assessment of the trade-offs between a technology or service's added cost and the related benefits to alternatives is often essential. It is, therefore, a necessary parameter for actors to shift their focus on the demand side of technology instead of the technology. Innovating new technologies and farming approaches can only prove effective if the newer ones are better than the older versions. The hype that comes with new technologies is often exaggerated beyond reasonable proportions (Ryan, 2020). This can mislead many farmers into buying newer technologies or adopting more recent farming practices, hoping to reap maximum benefits. When the focus is on technology, power dynamics and technological triumphalism emerge. ATPs, industrial-scale farmers, governments, and private sector companies may trick farmers or coerce them into buying and using their technologies in exchange for some benefits such as farm insurance programs, farm mechanization, mobile money, fertilizers, etc. To avoid such power dynamics from agriculture, efforts should be made to educate farmers to differentiate between technologies to adopt and use and how to use them. Government policies can protect smallholder farmers from the personal interest of ATPs and other actors (Arnold et al., 2001). Therefore, it is essential to start any new farming approach that involves using ICTs and other agriculture intervention programs by first focusing on the need that the intervention is supposed to address and not the need for the technology or farming technique.

Nevertheless, the need for better and timely climate information, better access to financial services, and the appropriate conditions for crop management, advisory services, valuable links to agricultural value chains, and so forth, in some instances, the introduction of ICTs and some other intervention programs will not meet all these needs. That is to say, when designing farming approaches that involve the use and exchange of knowledge for smallholder farmers (World Bank, 2011); it is vital to bear in mind that access refers to the affordability, service, and usage models that are most appropriate for the local, physical, environmental, social, political and socio-economic constraints. The specific mix of most appropriate and locally sustainable individual users depends on local needs and resources and is bound to change over time. This change will be due to the diversification of devices and services, making them even more affordable.

6.6 Being Aware of Gender and Social Differences in Terms of Use and Access

Under unfavourable conditions, CSA and ICT interventions can worsen rather than mitigate the existing socio-economic and political inequalities, including those between men and women. In Ghana and most parts of sub-Saharan African, women in rural areas face many significant setbacks or disadvantages in accessing and using ICT assets and services. Most farming practices and ICT designed projects to enhance rural access to information services are mostly owned or run by men. Important to note is that social issues go way beyond gender (Nwajiuba, Tambi, Emmanuel, & Solomon FARA, 2015); a complete understanding of the regional, national and local agricultural economy is vital. This ensures that ICT interventions programs and the use of innovative farming tools and approaches would not restrict the participation of poor rural farmers or producers to the extreme low end of the agricultural value chain. Design techniques that are pretty consistent and transparent and regulations guiding the investments of low-income countries should be implemented and adopted. Innovative or digital farming intervention programs usually require a robust, flexible, regulatory environment complemented by incentives to make investments. The use of ICTs and agricultural intervention programs require effective leadership (World Bank Group, 2017). These leaders must function both at the national and local levels where strategic and budgetary decisions are made. Their operation should model the effective use of technologies and build farmers' trust in their efficacy at the local level. Leaders are needed to break the social and economic disparities across all levels.

6.7 Recommendations

Based on the analysis of the findings from this thesis, the following recommendations are proposed for agricultural strategic decision-makers and stakeholders. These recommendations would help ensure the effective use of new farming practices such as CSA and CIS and define new ways to harness the power and potential of ICTs and BDA techniques that can significantly transform the ways climate data is processed and communicated smallholder farmers. Furthermore, adopting one, more, or all of these recommendations may help in the scaling up and out of smallholder farmers' agricultural productivity while mitigating climate change and developing climate resilience farming methods.

1. The first recommendation proposed is for relevant actors to focus their attention on overcoming key challenges that hinder the adoption and use of new farming technologies and approaches. One of these challenges is access to climate data. Governments and organizations should promote open data movements instead of leaving the data proprietary or in an inaccessible format. The collection and management of climate data should not be fragmented among government agencies, NGOs, private sectors, and agribusinesses. The reluctance of NMS and other climate data services to share data is a challenge that should be recognized. Public institutions and private sectors can play a critical role in promoting open climate data sharing and standards. The next challenge that needs to be addressed is skill barriers. Aside from barriers to using climate data, skill barriers that are so significant exist as well. Since many organizations find it challenging to hire individuals with the right expertise to harness the value of historical climate data fully, private and public sectors should play a role in helping to close these gaps in intellectual and technological resources. In addition, governments should encourage and prepare more students to develop intelligent remote sensors and build solid and effective BDA ecosystems. Finally, the issue of data privacy, data ownership rights and informed consent should be considered closely when dealing with any data. Companies and organizations such as Esoko in Ghana that offer data-enabled services to farmers should be explicit about seeking informed consent from farmers to use their data. Also, policies should be enforced to ensure that development practitioners who promote the use of ICTs by farmers educate farmers to understand how their data will be used and who owns their data.

2. The second recommendation is to focus on critical tasks that can help farmers reap the gains from using ICTs and BDA in CSA. Thus, to enjoy the potential of ICTs, countries and actors should focus on two major essential tasks.

   a. They should entirely focus on empowering poor farmers with access to information and communication services and assets that will not only protect their livelihoods and food security but will increase their productivity.

   b. ICTs should be effectively harnessed to enable them to compete in rapidly changing agricultural markets. This task can be achieved by implementing complex policies, innovation, capacity building, investment concerning beneficiaries and other important players. Also, governments and agricultural ministries can accomplish this task by encouraging the use and growth of sustainable ICT infrastructure and growing locally appropriate and affordable tools.

3. The third recommendation is for NMS, NGOs, governments and private sectors involved in climate data collection and processing to expand the use of data merging to fill the gaps that are found in historical climate records from meteorological stations and to encourage the use of the resulting high-quality data sets as a basis for the generation of localized historical forecasts.

4. The final recommendation is to encourage collaborative initiatives among those organizations and research scientists to improve communication of climate and weather information to smallholder farmers. They should also play a role in comparing and assessing the strengths and limitations of current communication methods and related training materials. Key objectives here will be to increase the accessibility to communication materials through online forums and identifying innovations in approaches that can address specific weaknesses in some techniques and tools.

7. Conclusion

This study explores how the generation and analysis of climate data using ICTs and BDA approaches can help to maximize agricultural productivity for small-scale farmers in CSA. The study used Ghana, which is a country in sub-Saharan Africa, as a case of interest. It aims to establish and understand the conditions under which the adoption of innovative farming approaches and tools by smallholder farmers can help them increase productivity while improving livelihoods and mitigating climate change. Given that climate is one of the critical determinants of agricultural processes in sub-Saharan Africa, an in-depth exploration was conducted on how climate data can be harnessed using the potentials of ICTs and BDA to generate valuable insights. The probe was done from the perspective of CSA and referencing CIS whenever needed. As evidence suggests, most countries in sub-Saharan Africa depend on rain-fed agriculture; thus, climate variability, climate change and food insecurity pose a real threat to the farming populations of these countries. While the aim of this study is not to study climate change and variability specifically, it has, however, explored these two dimensions to some extent because of their significance in increasing smallholder farmers' productivity. In CSA, the main pillars are: improving productivity, mitigating climate change, and reducing greenhouse gases in the atmosphere (Prasa et al., 2016). These three pillars are interrelated and depend on each other to a certain degree. For example, inadequate or poor climatic events result in low productivity, which exacerbates the problem of not meeting the SDGs of zero hunger, poverty, and climate action. In light of these, the study provides a broader picture of CSA and CIS and explains how ICTs can generate climate data for BDA techniques to act upon it. Using ICTs and BDA to extract the value of climate data and using the extracted value in CSA to help smallholder farmers make strategic farming decisions is insufficient to increase their productivity sustainably. Specific conditions that favour the use of climate information in CSA must be understood and addressed if smallholder farmers extract the most of the innovations. Thus, the research question for this study is: *under what conditions can the application of ICTs and big data analytics on climate data increase agricultural productivity for small-scale farmers?* This research question is addressed using a case study research design as a framework for data collection, followed by in-depth qualitative expert interviews and a systematic review.

Given the critical role that climate information plays in the agricultural sector in informing farming decisions and the adaptation of interventions and efforts to accelerate the transformation of new farming approaches to address daunting challenges, rightly look to ICTs and BDA as tools and techniques that can be used in CSA and CIS as part of the solution. Most countries in sub-Saharan Africa benefit from decades of research on ICTs as a means in agriculture to alleviate many socio-economic conditions of small-scale farmers through climate information and weather forecasts. ICTs such as mobile phones, radio, television and posters play a role in transmitting the collected and analyzed climate and weather information to local farmers. Satellites, NMS, and WMO help generate and store climate data, while BDA in combination with specific ICTs help in the climate data analysis process. Despite the long ongoing research on climate-centric agriculture in sub-Saharan Africa, the investment and innovation in production, translation and communication of climate information have not yet narrowed the central gap between the needs of smallholder farmers and the information that is haphazardly available from NMS in most sub-Saharan African. Evidence shows that there are a few critical weaknesses in the provision and delivery of climate information to farmers; however, these weaknesses continue to reinforce each other in specific ways. They also impede the progress in meeting the climate service needs of farmers to scale their productivity.

Findings further show that smallholder farmers can benefit from the use of novel farming tools and approaches through effective communication and face-to-face interaction. The case studies on the effect of PICSA on smallholder farmers in northern Ghana (Clarkson et al., 2019), Esoko (Schalkwyk, Young & Verhulst, 2017) and that of the case on the use of ICTs in Senegal (Westermann, Thorton & Forch, 2015) all point to the importance of climate and weather information in making farming decisions and using participatory communication processes when dealing with smallholder farmers, the majority of whom are illiterate. These direct communications and interactions should not only be with farmers, but they should involve all relevant actors in collecting, analyzing, and disseminating climate information. As AIS suggests, the active interactions and communication among the various actors constitute an innovation in agriculture. Considering the low skill set and knowledge of most smallholder farmers, periodic training with farmers through workshops can significantly enhance their knowledge in using ICTs to understand climate and weather information. Up-skilling and educating farmers will also lead to knowledge sharing among farmers, thereby creating innovative services in agriculture for both rural and urban farmers.

Key challenges such as gaps in historical climate data, data accessibility and quality, political influence, inequalities, and technological hype are pointed out as factors that could heavily hinder the outcome of using ICTs and BDA on climate data. This study points out that historical data gaps and climate data quality play a significant role in determining the generated insights and subsequent communication to farmers. When the collected climate data from meteorological stations contain little or significant data gaps, the analysis that would be done usually leads to inaccurate or misleading insights. Communication of wrong forecasts to farmers potentially leads to poor farming decisions (Coulibaly et al., 2015), leading to low farm yield at the end of the harvesting seasons. This data quality and historical data gaps in climate data should be closely examined and well mediated by responsible actors before conducting any intended analysis. Climate data quality and the historic data gap can be supplemented by merging data from satellites and local stations and analyzing the resulting data. Findings show the process of climate data collection and analysis and how the involvement of various actors can streamline the process in favour of smallholder farmers. ICTs are used to generate and collect climate data at the onset. The collected climate data is then analyzed or translated using BDA techniques. The resulting climate and weather predictions are communicated to farmers through ICTs. Once the information is communicated, farmers act on the weather forecasts to base their farming decisions to meet CSA pillars concurrently. However, challenges such as inequalities, political influence and technological triumphalism significantly impede the potential for success of ICTs and BDA in CSA. These challenges can best be overcome through direct and active participation of actors, including governments and agricultural ministries, to develop and implement policies tailored towards curbing the personal interest of certain actors in using smallholder farmers as tools to achieve their own goals.

The conditions under which smallholder farmers can benefit from using ICTs and BDA on climate data within CSA are identified. Firstly, five key factors need to be met. These are: first, the quality of the climate data and accuracy of weather forecasts should, knowledge and skills of small-scale farmers, effective communication, training, and interaction, ensuring effective collaboration among actors as proposed by the AIS framework, and finally, developing national agricultural policies using the NIS perspective. Secondly, the gains derived from ICTs and BDA should be adequately channelled to smallholder farmers to ensure that they get the maximum share of the benefits. Third, all other actors should put their efforts together to uplift the poor farmers. Another condition is to correctly identify ICT drivers and barriers and use digital tools and new farming techniques as a means to an agricultural end. The fourth condition is to actively engage with smallholder farmers and combine the various communication channels to avoid information asymmetry among the various farmer groups. Fifth, instead of concentrating on the hype and demand side of technologies and farming approaches, actors need to use appropriate technologies tailored to farmers' needs. Moreover, last but not least, agricultural policymakers, governments, and other actors (Gubbels, 2013) should be aware of the gender and socio-economic differences in terms of access and use of technologies and information services.

Growing recognition of the urgency of climate challenges calls for a new examination of the current state of ICTs, BDA, CSA and CIS in Africa relative to what is known about the needs of smallholder farmers as well as opportunities at an international and national level to address the longstanding obstacles to better align farming practices with the needs of farmers and the key actors that support their goals. This study has aimed to contribute to the discussion of climate change and food insecurity by addressing the scalability of what is currently understood as good farming practices to meet the needs of smallholder farmers. It also highlights the conditions under which smallholder farmers can maximally benefit from the gains of using climate data and novel technologies to increase productivity, mitigate climate change, reduce or eradicate greenhouse gases, and improve livelihoods and income. Future research is wise to study the conditions under which smallholder farmers may benefit from new farming approaches and technologies and investigate the consequences of power dynamics in agriculture. It is also interesting to research to understand to what extent developing countries are using new farming techniques to boost their agricultural economic output and eradicate rural poverty.

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9. Appendix

9.1 Link To Interview Transcripts

https://drive.google.com/file/d/1ohUbfNRUn_PtLheTyc0h3rRDUGq1FuLN/view?usp=sharing

9.2 Link to Code Book

https://drive.google.com/file/d/1ohUbfNRUn_PtLheTyc0h3rRDUGq1FuLN/view?usp=sharing

9.3 Link To Interview Protocol

https://drive.google.com/file/d/1erMocwWtePYbo-_weZYFW-abwBcX-xix/view?usp=sharing