Drivers and barriers to the adoption of Climate Smart Agriculture (CSA) Technologies by smallholder farmers in South Africa: the role of technology characteristics and business models




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Thesis

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Drivers and barriers to the adoption of Climate Smart Agriculture (CSA) Technologies by smallholder farmers in South Africa: the role of technology characteristics and business models

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To my daughter, Mmatladi Lebogang Senyolo,
and in loving memory of my granny, Mmatladi Rachel Phaahlemosadi Dikotla-Teffo

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General Introduction

CHAPTER 1

1. General Introduction

1.1 Climate change related problems and climate smart agriculture (CSA)

For the past few decades, climate change mitigation and adaptation issues have become subject of intense global discussions (Elum *et al.*, 2017). Accordingly, on a global level, there is a growing recognition of the need to reconcile environmental protection, invest in smallholder agriculture, reduce carbon emissions, improve food production and productivity, and reduce vulnerability to the predicted impacts of climate change (Meinzen-Dick *et al.*, 2013). However, Adger *et al.* (2003) note that while climate change is a global problem, the need for adaptation is higher among developing countries where susceptibility is likely higher.

Agriculture forms a substantial part of local economies in sub-Saharan Africa (SSA) (Pereira, 2013). The agricultural sector is a source of food security and livelihood for many poor people in rural communities, making it necessary to safeguard livelihoods of rural smallholder farmers (Bryan *et al.*, 2009; Elum *et al.*, 2017; Makate *et al.*, 2019). Yet, smallholder agriculture in Southern Africa is extremely vulnerable to climate variability and change (Makate *et al.*, 2019) as the region is prone to extreme weather events such as floods, drought and heat waves (Masih *et al.*, 2014; Nhemachena & Hassan, 2007). For this reason, African governments are keen to take a shared action to accomplish a balance between improved livelihood of farmers and climate resilience in the face of climate change risks (Gandure *et al.*, 2013). Also, individuals and societies in those countries engage in various response mechanisms to become more resilient to the impacts of changing climate (Elum *et al.*, 2017; Mpandeli *et al.*, 2015).

Climate change impacts are coupled with an ever increasing population which requires a boost in the productivity of land and water sustainably than current practices (Inocencio *et al.*, 2003; Taneja *et al.*, 2014). Both the challenges to produce more food for an increasing population in the region and climate change call for a transition to a more sustainable agricultural system and necessitate new management approaches for the sustainable utilisation of natural resources (Mathews *et al.*, 2018; Shrivastava, 1995). Hence a focus on approaches to increase productivity of resources needs to increase under environmental and sustainability constraints (Freibauer *et al.*, 2011).

One of the approaches promoted as way to unravel this dilemma is Climate Smart Agriculture (CSA), aimed at achieving sustainable agricultural development for food security under climate change using technical, policy and investments conditions (FAO, 2013). For example, the planting of drought-tolerant seed varieties is among the most common climate-response strategies that farmers employ (Elum *et al.*, 2017; Makate *et al.*, 2019; Senyolo *et al.*, 2018).

Largely, CSA "includes proven technologies and practices such as water management, intercropping, conservation agriculture, crop rotation, mulching, integrated crop-livestock management systems, agroforestry, and improved pasture and grazing management" (Sullivan *et al.*, 2013). Moreover, CSA is context dependent (Garrity, 2012; Zilberman *et al.*, 2012) implying that regions have their own climate related challenges with specific consequences for planting methods (i.e. agroforestry and crops), water, nutrients etc. Accordingly, particular regions require specific CSA interventions (Taneja *et al.*, 2014).

This study is set within the context of the transition to CSA in South Africa (SA). CSA is recognized as an integrated approach that can help address the uncertainty accompanying a changing climate and climate risk management (Mathews *et al.*, 2018). Long *et al.* (2019) noted that CSA fits within the concept of sustainability transition since it is envisioned to provide collective goods such as climate change mitigation and other environmental outcomes whilst it also encourages modification of behaviours by those involved.

1.2 CSA technological innovations (CSATIs) as an element of CSA

Basically, CSA comprises a number of technological, policy and institutional interventions. The focus of this study is on technological interventions. Technological innovation has the potential to help deal with climate change, contributing to an agricultural sector that is climate resilient with low greenhouse gas (GHGs) emissions (Doranova & Miedzinski, 2013; Jacobs *et al.*, 2011). CSA technologies which can be hardware, software and org-ware, provide solutions to climate-related problems in agriculture[1,2]. Those solutions include the potential to increase agricultural productivity and the adaptive capacity of human and natural systems as well as reducing emissions or enhancing carbon storage (McCarthy *et al.*, 2011). Thus, CSA innovations are defined as "new products, services or techniques, or improvements to existing products, services or techniques which help achieve CSA objectives" (Long *et al.*, 2019).

Kaczan *et al.* (2013) posits that agricultural technologies and practices that constitute a CSA approach are usually not new and mostly coincide with those of sustainable agriculture and intensification. Nonetheless, the authors maintain that under a CSA approach, technologies are evaluated for their ability to create increases in productivity, resilience and mitigation for specific locations, assuming the anticipated impacts of climate change. A wide range of these technologies and practises exists and include water management (harvesting and saving), crop management, agroforestry, and conservation agriculture.

[1]See http://www.wageningenur.nl/en/project/Climate-Smart-Agriculture-CSA-Booster.htm. Accessed on July 2014.
[2] UNFCCC, 2014. Technologies for Adaptation in the Agriculture Sector. Technology Executive Committee Brief #4

1.3 Progress in promoting adoption and use of Climate Smart Agriculture (CSA)

The South African agricultural sector faces a scarcity of water, which will increase as a result of climate change (Baleta & Pegram, 2014). About two-thirds of SA is arid or semi-arid (Kamara & Sally, 2003), meaning efficient management of water resources is a national priority. Numerous research conducted in SA indicated existing and potential water-related impacts of climate change (Benhin, 2008; Biazin *et al.*, 2012; Blignaut *et al.*, 2009; Bryan *et al.*, 2009; Gbetibouo & Hassan, 2005; Joshua *et al.*, 2014; Mpandeli *et al.*, 2015; Ziervogel *et al.*, 2010), thereby warranting exploration of interventions to reduce consumption and manage supply in order to maintain water security for the agricultural sector (Mukheibir, 2008; Venot *et al.*, 2014). Our study was conducted in a water-stressed area and consequently water constitutes the core climate impact, hence the focus is on CSA technologies that contribute to these particular climate risks, i.e. in terms of adaptation to water stress and reducing GHG emissions (where necessary). In SA, the issue of climate adaptation came to the fore given the country's urgent socio-economic developmental needs and threatened ecosystem services (Ziervogel *et al.*, 2014). Consequently, adaptive responses that diminish the vulnerability to current as well as future climate variability and change were noted to be essential.

It is clear that the establishment of improved agricultural technologies and management systems are important ways to increase the productivity of the farmers (Doss, 2006; Ismael *et al.*, 2002). Gouse *et al.* (2005) and Beyers *et al.* (2002) for instance posit that farmers who adopted Bt cotton in SA appeared to be more technically efficient than those who do not. Thus, the adoption of the Bt cotton by small-scale farmers in the Makhatini Flats of KwaZulu Natal saw them enjoying benefits such as an increased yield and a decreased use of insecticides which led to improved income for those farmers (Gouse *et al.*, 2005). Analogously, CSA technological innovations (CSATIs) at farm level have the potential to respond to climate change challenges whilst also enhancing the livelihoods of farmers. However, one of the main challenges in SA and elsewhere is the inadequate adoption of these technologies in order to actually enhance and secure CSA (Jack, 2009; Kaczan *et al.*, 2013; McCarthy *et al.*, 2011; Shikuku *et al.*, 2017). Therefore, the reasonable question is what are the drivers and barriers to the adoption of potential CSATIs. In the same light, several considerations can help to understand what enable and/or hinder farmers to adopt the potential CSATIs. For instance, consideration of farmers' abilities to implement adaptation strategies and costs of implementing farming practices can shed light in terms of what is feasible and in each context (Shikuku *et al.*, 2017). Also, Kasier et al. (2010) cited in (Shikuku *et al.*, 2017) maintained that pecuniary and non-pecuniary costs affect human behaviour. Most farmers in developing countries are poor and often their focus is to realize economic profitability (Antle & Diagana, 2003; Heath & Binswanger, 1996); hence they are likely to be disinterested in ecological sustainability in the short run. Similarly, Tinker and Morris (2009) posit that apart from environmental regulation, the profitability of farming is among the key drivers for investing in new precision agricultural equipment and systems. In light of the above, sufficient insights are needed on barriers to adoption and how those barriers influence the adoption of potential technologies and practices. Understanding technologies and practices that farmers favour or disfavour regardless of their struggle to adapt to extreme weather events associated with climate change and variability is crucial to inform transformation of Africa's agriculture in the face of climate change. This thesis argues that data on CSA in the context of SA is also necessary to foster CSA take-off on the African continent (Mutamba & Mugoya, 2014). Overall, this thesis presents its contribution first by noting that agriculture is a key sector in developing countries in general, and Africa in particular. The thesis further highlights that climate change impacts agriculture significantly, and display CSA as a potential response to the climate change related impacts whilst underlining that CSA is not implemented to the sufficient degree. Consequently, the subsequent subsections present the research questions that the thesis will address, the theoretical background of the thesis, the contributions that the current thesis makes and end with the outline of the whole thesis.

1.4 Theoretical Background

In this thesis, various theoretical perspectives are used to shed light on the drivers and barriers to the adoption of climate smart agricultural technologies by smallholder farmers. Climate change represents a serious threat to agriculture, requiring increases in resilience to climate impacts and potential reductions in GHG emissions. Fundamentally, the various theoretical perspectives have highlighted the fact that adoption of technologies (i.e. climate smart agricultural technologies) is dependent on the interaction of the business models that are used by the agri-technology providers, the characteristics of such technologies and the context as well as the socio-economic characteristics of the concerned farmers.

Innovations in agriculture have been previously noted for their role in industrialisation and recently for their prospects to respond to climate change (Lybbert & Sumner, 2010; Pardey *et al.*, 2010). Specifically, technological innovation is highlighted as a central response to the challenge of climate change, both in the African continent and globally (Ekins, 2010; Msangi *et al.*, 2012). Rogers's theory of innovation diffusion provides a foundational understanding of adoption theories (Rogers, 1995), and as a result the theory has been used broadly across disciplines to comprehend and predict change. According to Rogers (1995) an idea, practice or object that is perceived as new by an individual or other unit of adoption is considered as an innovation regardless of whether that idea, practice or object is objectively new. Thus, it is the perception of that novelty that matters (Straub, 2009). Theory on adoption on the other hand, explores the individual and the choices an individual makes to accept or reject a specific innovation. As research and policy discourses about the impact of climate change on the agricultural sector evolve, CSA has become an important topic and concept for researchers, companies and policy makers alike. CSA technologies and practices at field and farm level have the potential to reduce the high emissions associated with conventional irrigation systems (Scherr *et al.*, 2012) and to realize the "tripple win'' objectives (Taneja *et al.*, 2014), i.e. both economic, environmental and social impact on the livelihood of farmers, their communities and the environment at large.

Drawing from the concept of CSA, CSATIs include technologies which seek to increase productivity of land, water, nutrients, energy, etc., while reducing the risk of climate change (FAO, 2010; Scherr *et al.*, 2012; Taneja *et al.*, 2014). It can take both a curative or preventative form (Rennings, 1998). For this reason, we conceptualise CSATIs as eco-innovations. Eco-innovation is defined as a process of developing new products, processes or services which provide customers and businesses added economic value while considerably reducing the environmental impact (Fussler & James, 1996; Kemp & Pearson, 2008; Nnaji & Igbuku, 2019). These innovations can be developed by firms or NGOs, can be traded on the markets and can be technological, organisational, social and institutional in nature (Rennings, 1998).

Whilst the concept of eco-innovation may offer some insight in the characteristics of CSATIs, it alone does not provide a basis from which to explore ways to maximise their impact and usefulness. It is increasingly recognised that the mere adoption of technological innovations may not lead to optimal outcomes, due to mismatches between technological innovation design and the contexts within which these technologies are ultimately employed. Alter (2002) argues that the technology adoption process is a route of adaptation and appropriation. Therefore, technology users will likely adopt it if it is compatible with their objectives and can be aligned with their practices (Johnson *et al.*, 2003). Kontogiannis and Embrey (1997) for instance state that lack of user participation in the design process of technologies result in a disparity between the potential and actual benefits of technology adoption and argue that user-centred design approaches can be used to address these drawbacks.

CSA technologies, like other eco-innovations, have to be used 'appropriately' and if users (farmers) do not utilise them in a specific way then they do not benefit from them. Therefore, a structured top-down approach to innovation development may not be adequate and a bottom-up approach may increase user acceptance of new technologies. Since the right technology adoption by farmers is key in case of CSA, the concept of user-centred innovation was also considered in this PhD project. This was considered necessary as it offers a perspective through which the design and adoption of CSATIs with input from both the technology providers and end-users can be analysed. User-centred innovation is an important perspective on CSA technology adoption, as previous research has highlighted that the involvement of end-users in the design of technologies can increase their impact (Johnson *et al.*, 2003; Kontogiannis & Embrey, 1997; Sthapit & Rao, 2008). Klerkx and Leeuwis (2008) for instance indicate the importance of demand articulation in clarifying demand and supply. The authors however acknowledge that establishing relationships that will foster demand-driven innovation processes is challenging for both the supply and demand parties. We hypothesize that one way of realizing this is through the exploration of the integrative approach between agricultural technology providers and farmers. Since this area has up to now received less attention, especially in the South African agricultural sector, we want to bridge this gap in the literature. In the context of CSA technology adoption in SA, it is expected that user-centred innovation can maximise the benefits of CSA technologies by enhancing their adoption by farmers.

By combining the concepts of CSA, eco-innovation and use-centred design at the level of the business strategies of companies, this research project was able to provide several contributions. Regarding the emerging concept of CSA itself, this research contributes to its conceptualization in theory and in practice, especially in the context of SA. Although user-centred innovation is a concept that has been applied in the context of agricultural practices in developing countries (Sthapit & Rao, 2008), its application in the context of climate change related technology development is rather new. Further, the combination of user-centred innovation approaches to CSA challenges within the African context is rather new as well. It enables us not only to apply the concept of user-centred innovations in the context of CSA in SA, but this context also informs a theoretical contribution to the concept of user-centred innovations itself.

1.4 Research Questions

The current study seeks to explore 1) the drivers and barriers to the adoption of CSA technologies by smallholder farmers in SA and 2) highlight the actions needed to tackle these barriers and enhance the diffusion and adoption of CSA technologies and practices among smallholder farmers. This aim led to the main research question of this PhD thesis: What drives and/or hinders the adoption of high potential CSA technologies in SA and how can adoption by smallholder farmers be enhanced?

Technology adoption studies can be undertaken from various perspectives, including the policy and institutional level (Taneja *et al.*, 2014), the technological level, and the company level of farmers (supply) and (multinational) enterprises (demand). In this PhD thesis, the focus was on the company level of the technology provider as a commercial actor who is trying to sell CSA technologies related to water use as well as focusing on farmers who are expected to adopt these technologies in order to improve their livelihood and reduce the effects of climate impacts. This thesis analysed the drivers and barriers for CSA technology adoption, both from the perspective of technology providers and farmers, and the effectiveness of specific strategies (e.g. use of public private partnership) to enhance the adoption of an example of CSA technology adoption (i.e. adoption of drought-tolerant seed technology) in the context of SA.

To achieve the aim of the current study and to answer the main research question of this PhD thesis, four sub-questions guided the study. The first sub-question:1. What specific CSA technologies related to water use and management are available in SA and what are their characteristics? This question primarily serves as a context of the research project to indicate the specific climate related challenges SA faces, the impact on specific sectors/crops, and available technologies that are potentially able to address these challenges. The rationale for this first research question was based on the premise that an understanding of the CSATIs that have been introduced and promoted farmers as well as their characteristics could highlight the challenges and opportunities for effective use of those technologies and practices.

The second sub-question: What are the main drivers and barriers to the adoption of CSA technologies by smallholder farmers? This question is intended to better understand smallholder decision-making about drought-tolerant seed varieties as an example of CSA technology, in order to pinpoint how opportunities might be created to assist farmers in implementing CSA. The rationale behind exploring the smallholder perspectives was based on the argument that understanding the barriers and drivers of adoption of the promoted CSATIs among smallholder farmers in SA may assist in targeting current CSATIs or redesigning them to suit the preferences and particular circumstances of farmers to safeguard adoption and sustainability.

The third sub-question: What factors enable or hinder the ability of business models used by agri-technology providers in SA to diffuse CSATIs? With this question, the aim was to explore the factors that affect the ability of CSA technology providers to diffuse CSATIs to smallholder farmers at the base-of-the pyramid (BoP), through examining their business models. The rationale for this question was based on the reasoning that adoption and diffusion of CSATIs is impacted by both supply and demand factors, and as such overcoming barriers to adoption of these technologies must involve tackling both supply and demand sides.

The last and fourth sub-question: How can CSA technology adoption by smallholder farmers be enhanced? The aim here was to examine how public private partnerships (PPPs) can enhance technology adoption by smallholder farmers and how hindrances faced by the partnership in enhancing technology adoption can be overcome and opportunities leveraged. The rationale was to investigate the efficacy of the intervention designed to increase technology adoption.

1.5 Research Context and Approaches

To answer the research questions outlined in the sub-section above, the study employed a combination of quantitative and qualitative research methods. According to Ackroyd and Hughes (1992) none of the approaches is distinctly better to the other in all aspects. Data were gathered through literature, exploratory in-depth interviews and by surveys, as elaborated in each of the chapters.

The first research question in chapter 2 was addressed by reviewing key literature covering the specific climate challenges that SA faces, the broader CSATIs that were noted to be available to deal with these challenges, and the different categories available to characterise these CSATIs. The review was used to inform the development of a framework for categorising technological innovations. Following this, primary data was gathered through semi-structured interviews with several groups of stakeholders including governmental officials, researchers (both from state-owned research institutions (e.g. WRC, ARC) and selected universities), private sector, farmer organisations and NGOs. The interviews provided data on specific CSATIs used within the South African context and the key factors noted to impact their adoption. The framework for categorising CSATIs was then applied to explore the key characteristics of the available CSATIs, and how these characteristics may impact adoption.

The second research question was addressed through a survey approach. The study explored factors influencing smallholder farmers' decision-making and adoption of CSA technology (i.e. drought-tolerant seed varieties). The study was carried out in Vhembe, Capricorn, and Greater Sekhukhune in Limpopo Province (Figure 1). Capricorn District is situated as a stopover between Gauteng (Johannesburg) and the northern areas of Limpopo, and between the northwestern areas and the Kruger National Park. It forms a gateway to Botswana, Zimbabwe and Mozambique and covers 21705 km^2. Greater Sekhukhune District covers 13528 km^2 and Vhembe District covers 25597 km^2. For most of Limpopo province, the bulk of precipitation occurs in summer, with annual rainfall ranging between 400-600 mm (Tshiala *et al.*, 2011). Limpopo Province was selected as the study area because of its high climatic variability and largely arid to semi-arid nature; meaning CSA technologies and practices that reduce the impacts of droughts, water scarcity and moisture stress are needed. Many of the agricultural activities are undertaken by smallholder farmers. Furthermore, our decision concerning the study area and the technology in question was also informed by the existence of political organisations, research institutes, and NGOs' determination to promote the use of drought-tolerant seeds to address moisture stress, mitigate against water scarcity and to improve food security and livelihood of smallholder farmers. The analysis is based on data collected through farmers' survey that captured farmers' socio-economic characteristics, the external environment which is presumed to influence their technology adoption decisions and their perceptions of the CSA technology specific attributes. Focus groups discussions and key informant interviews augmented the data used.

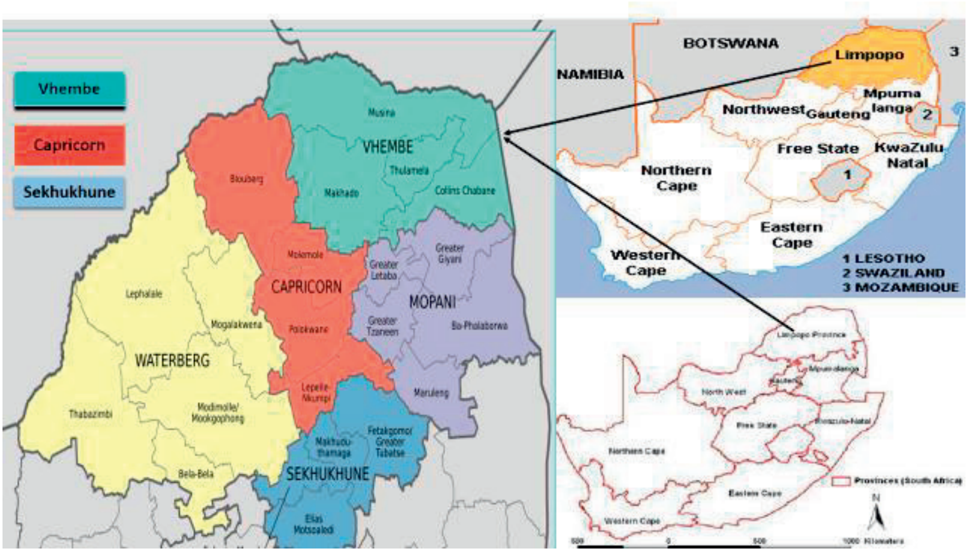

Figure 1: A map showing the study area where data was collected.

To collect the primary data used in chapter 3 of this thesis, a multi-stage sampling procedure was employed. Consequently, three districts of Limpopo province, where drought-tolerant seeds were introduced and/or promoted, were selected. CSA technologies promoted and introduced in the study area were first established through an exploratory study (Senyolo et al., 2018), then followed by the farmers' survey reported in chapter 3 of this study. Using the lists from agricultural local extension officers in each district, a sample of 196 farmers were randomly selected based on probability proportionate to size per district (see table 1) as well as farmers' willingness to participate in the research. Subsequently, 87, 71 and 38 farmers in Vhembe, Capricorn, and Greater Sekhukhune respectively, were administered structured questionnaires by either trained enumerators or the PhD candidate. The questionnaire comprised 4 sections which covered (1) farmers' characteristics and socio-economic realities, (2) institutional support, (3) farmers' knowledge on climate change and CSA technologies and practices and (4) farmers' perceptions of CSA technology specific attributes. Prior to administering the questionnaires, focus group discussions (FGDs) (N=5) comprising 45 participants in total were held to gain initial insights on the farming activities in general and main crops of farmers in particular, as well as key issues affecting the targeted respondents [See (Bryman, 2008; Mugi-Ngenga *et al.*, 2016; Ubisi *et al.*, 2017)]. Data for this study was collected between February 2016 to February 2017.

The third research question was addressed through an in-depth qualitative approach. Thus, chapter 4 intended to answer the question: What factors enable or hinder the ability of business models used by agri-technology providers in SA to diffuse CSATIs? The in-depth qualitative approach was found to be an appropriate research design as (1) little is known of CSA technology providers in the developing countries context, while (2) our research questions were of ‘why’ and ‘how’ nature. For this study we relied on data from in-depth interviews with agri-technology providers (N=10), which were triangulated with the literature in the fields of CSA, technological innovations and business models. The results facilitate understanding of the complexity of adoption, which often is explored from the demand side (e.g. farmers’ perspectives) only.

Chapter 5 answered the fourth research question of this thesis and was addressed through the use of a case study. The aim was to investigate the impact and efficacy of intervention(s) designed to enhance technology adoption. Therefore, this study examined the role of Water Efficient Maize for Africa (WEMA) project in enhancing technology adoption by smallholder farmers in SA. By exploring the WEMA case, the study sought to examine how public private partnerships (PPPs) can enhance technology adoption, and how they contribute to reducing the impact of climate change. Furthermore, through this case, barriers were identified within the WEMA project, that are likely to impact its efficacy and impact on the targeted output (technology development, deployment and adoption) and the beneficiaries (smallholder farmers). In addition, this specific study provides implications for effective outcomes on the formation and implementation of regional level PPPs.

1.6 Contributions of the thesis

The present study offers several contributions to the literature.

The novelty of this thesis lies in the combination of various analytical techniques and approaches to analyse drivers and barriers to the adoption of CSATIs within smallholder farming in developing countries. This thesis furthermore contributes in terms of empirical information to the CSA transition debate, and more specifically concerning the adoption of CSATIs in smallholder agriculture. Previous research highlighted the idea that overcoming barriers to adoption of CSATIs must involve tackling both supply and demand sides (Long *et al.*, 2017; Montalvo, 2008). The argument here is that supply and demand side barriers are likely to interact. However, few studies largely based on the western context explicitly explored the interrelations between supply and demand side barriers (Blok *et al.*, 2015; Long *et al.*, 2016; Long *et al.*, 2017). This study therefore fills this gap by analysing the drivers and barriers to adoption of CSATIs in smallholder farming from the perspectives of both the smallholder farmers and agri-technology providers. The combined perspectives of both the smallholder farmers and agri-technology providers have not yet, to our knowledge, been applied in adoption studies concerning CSATIs in developing country context.

This thesis started first by establishing the context through its first study where the promoted CSATIs in the South African context were ascertained. The foundational work was found to be important given that proponents of CSA advocate for context specificity [see (Garrity, 2012; Zilberman *et al.*, 2012)]. Engaging different stakeholders that work in the area of CSA in SA helped the investigators in this research to gain insights about how different technologies were introduced and brought to farmers. The thesis fits within several strands of literature including studies that assess determinants of adaptation to climatic risks (Bryan *et al.*, 2009; Deressa *et al.*, 2009; Shikuku *et al.*, 2017); those that look at the relationship between farmers' perceptions and adoption of agricultural technologies (Elum *et al.*, 2017; Rankoana, 2016; Shikuku *et al.*, 2019); and those studying adoption of climate smart agricultural technologies (Mwongera *et al.*, 2017; Mwungu *et al.*, 2018). Furthermore, the thesis further expands our understanding regarding business models and their associations with sustainable innovations. Understanding the business side is equally vital since the adoption and diffusion of CSATIs is impacted by both supply and demand factors. We argue that a business model approach could facilitate the exploration of the interrelations between supply and demand side barriers. This approach also explains the core logic of agri-technology providers' businesses and allows a reflection on how to capture value from providing new products and services that add value for the smallholder farmers in this case (Bocken *et al.*, 2014; Teece, 2010). Furthermore, the thesis provides further arguments for the need to provide smallholder farmers with credit for production purposes, over and above providing them with different CSA technologies. This is necessary as our study indicates that core requirements of smallholder farmers within base-of-pyramid go beyond demonstrating the impact of CSA technologies (as it is the case in western contexts).

Lastly, the thesis delved into the effectiveness of intervention(s) designed to increase technology adoption through exploration of a case by examining the role of Water efficient maize for Africa (WEMA) project in enhancing technology adoption by smallholder farmers in SA. By exploring the WEMA case, the thesis seeks to examine how PPPs can enhance technology adoption, and how they contribute to reducing the impact of climate change. In doing so, the thesis identifies the barriers faced within the WEMA project that are likely to impact the efficacy of and impact of PPPs on the targeted output and the beneficiaries such as smallholder farmers. The thesis also provides strategic implications on designing the PPPs, by providing further arguments for the need to take account of specific country contexts especially for the PPPs that are formulated at a regional level.

1.7 Outline of the thesis

This thesis comprises six chapters, including the general introduction (see figure 1). Overall, earlier and parts of this research were presented in international conferences to disseminate the results and to get feedback from other scholars. Specifically, earlier draft of Chapter 2 was presented at a Global Cleaner Production and Sustainable Consumption Conference held in Sitges, Barcelona in Spain in 2015 and earlier draft of Chapter 3 was presented at the combined 26th Annual IFAMA World Conference and 12th Wageningen International Conference on Chain and Network Management in Aarhus, Denmark in 2016. Furthermore, Chapters 3, 4 and 5 have been prepared and submitted to journals, whilst Chapter 2 have been published in *Journal of Cleaner Production,* a ISI Q1 and peer-reviewed journal as a stand-alone article.

In Chapter 2 an exploration of the specific CSA technologies related to water use and management that are available in SA was conducted. It identifies their characteristics, as well as their context of application and key factors that are assumed to impact their adoption. Chapter 3 empirically explores the factors influencing smallholder farmers' decision-making and adoption of CSA technology (i.e. drought-tolerant seed varieties). The chapter uses survey data collected from smallholder farmers (N=196) to analyse the drivers and barriers to adoption of drought-tolerant seed varieties for maize as one of the CSA technologies and practices considered relevant for smallholder farmers under rain-fed agriculture.

Chapter 4 goes further to explore the agri-technology provider's business models within smallholder farming context in SA using in-depth interviews (N=10) in order to understand CSA technology dissemination to smallholder farmers at the base-of-the-pyramid (BoP). The critical factors which enable or hinder the ability of business models used by agri-technology providers in SA to diffuse CSATIs are highlighted.

Chapter 5 uses a case study analysis to investigate the impact and efficacy of the PPP as an intervention designed to improve technology adoption and explores the windows of opportunities available in smallholder farming to enhance CSA technology diffusion and adoption.

In Chapter 6, the main conclusions emanating from the thesis are discussed. The outcomes and implications of the outcomes of this research study are discussed at a broader scale, and the specific recommendations to policy makers and technology providers are drawn. Areas of further research challenges to enhance CSA technologies and practices in developing countries in general and in SA in particular are identified and outlines.

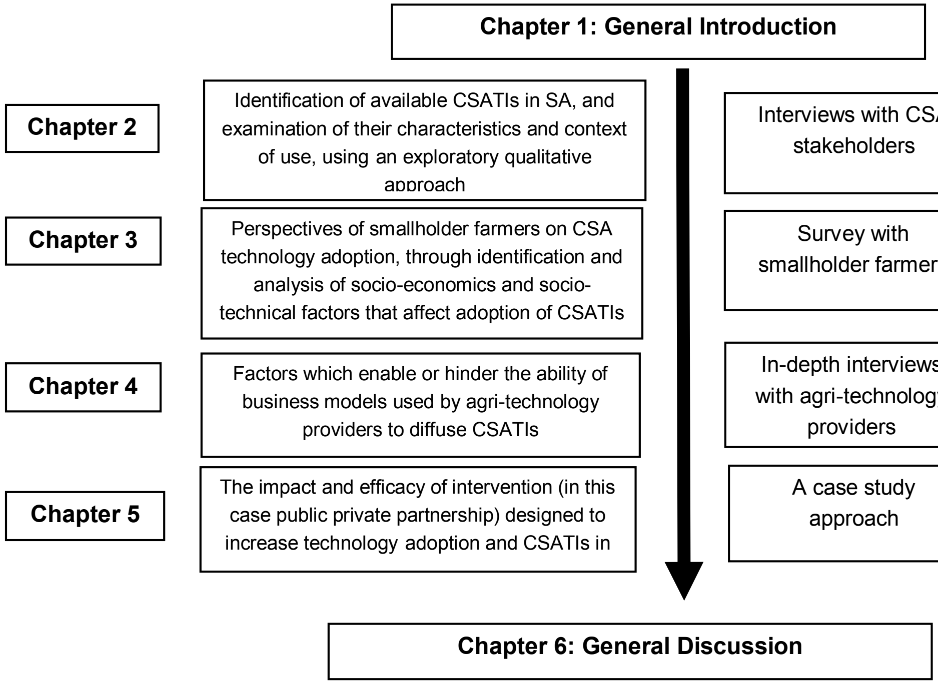

Figure 2: Thesis outline

2

How the Characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa

This chapter is based on: Mmapatla Precious Senyolo, Thomas B. Long, Vincent Blok, and Onno Omta (2018). "How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa.": published in *the Journal of Cleaner Production* 172 (2018): 3825-3840. https://doi.org/10.1016/j.jclepro.2017.06.019

CHAPTER 2

1. Introduction

Climate change threatens the agricultural production and food security of developing countries in complex ways that demand environmentally friendly innovations. Africa's agriculture is vulnerable to climate change (Arslan *et al.*, 2015; Juana *et al.*, 2013), owing to the impact of climate variables such as temperature, humidity and precipitation (IPCC, 2007, 2011), its sensitivity to projected changes and low adaptive capacity (Benhin, 2008; Hellin *et al.*, 2012). Many climate impacts relate to water and therefore, consideration of how water is managed, especially in rural and agricultural sectors, will be key to climate change adaptation strategies (Hardelin & Lankoski, 2015; Water, 2010) Climate impacts will worsen water scarcity, water quality problems and related socio-economic development issues in South Africa (SA) (New, 2002; Schulze, 2011). Lack of water for agricultural activities remains a major threat to food security, poverty, and sustainable development (Kahinda & Taigbenu, 2011). For instance, droughts which mainly result from the variability in rainfall during the periods of climate stress are a large factor in augmenting food insecurity (Mpandeli *et al.*, 2015). These authors mentioned that drought often affects agricultural production in various provinces of South Africa including Limpopo, Free States, parts of Western Cape and Northern Cape. This underlines the importance of understanding the characteristics and availability of different CSA technologies and practices to manage these climate change related threats (Asfaw & Lipper, 2016). The effects of water scarcity include loss of livestock, low yields and shortage of seed for subsequent cultivation (Maponya & Mpandeli, 2012b). Evidently, shortage of water and droughts in the 1981/1984, 1988/1989, 1991/92, 2004 and recently during 2014/2015 seasons had significantly larger negative impacts on crops and livestock volumes and consequently on food security and livelihood in general (Mpandeli *et al.*, 2015). Predicted impacts of climate change and the dominance of rain-fed agriculture in SA, mean that climate change poses a sizeable challenge characterised by poor and unreliable rainfall, frequent droughts and periodic flooding, especially within the context of an increasing population (Bogdanski, 2012). These challenges necessitate the uptake of sustainable technological innovations (Karakaya *et al.*, 2014). The uptake of these innovations depends upon an understanding of the intersection of climate change, technological innovation and sustainable development in order to foster transitions to sustainable bio-economies at global scale (Ingrao *et al.*, 2016).

Climate Smart Agriculture (CSA) recently gained prominence as a response to climate change (Asfaw *et al.*, 2016; Campbell *et al.*, 2014). CSA strives to sustainably increase agricultural productivity, national food security and incomes by adapting to and building resilience to climate change and by reducing greenhouse gas (GHGs) emissions relative to conventional practices (FAO, 2010, 2013). CSA includes proven technologies and practices such as water management, intercropping, conservation agriculture and agroforestry (Rojas *et al.*, 2014; SA, 2011; Sullivan *et al.*, 2013). CSA consists of technological, policy and institutional interventions (Taneja *et al.*, 2014), and is context dependent (Zilberman *et al.*, 2012). Accordingly, particular regions require specific CSA interventions (Asfaw & Lipper, 2016). SA does not have a policy on CSA, but awareness is high and is likely to increase when CSA policies are put in place at national, provincial and local levels (Mnkeni & Mutengwa, 2013). This is reflected by the number of projects and initiatives in SA whose objectives and activities are consistent with CSA principles. Consequently, understanding what CSA technological innovations (CSATIs) have been introduced or promoted and their characteristics could highlight challenges and opportunities for effective adoption of these technologies and practices.

Understanding the challenges and opportunities for effective technology adoption is important, as smallholder farmers in Africa are particularly exposed to climate change and need CSA (Grainger-Jones, 2011). Frequently, the term ‘smallholder’ is used interchangeably with ‘small-scale’, ‘resource poor’ and sometimes’ ‘peasant farmer’, however, it refers to farmers’ limited resource endowment relative to other farmers in the sector. These farmers habitually have an average farm size of 0.5 to 2 ha and operate under various constraints related to capital and labour, availability of inputs, or lack of knowledge (Drechsel *et al.*, 2005b). In SA, these farmers occupy the less developed and less resourced agriculture within small-based plots of land on which they grow subsistence crops and one or two cash crops (DAFF, 2012; Thamaga-Chitja & Morojele, 2014). Whilst the smallholder farmers have an important role in improving household food security (Wiggins & Keats, 2013), they face new challenges driven by climate change, environmental and agricultural policy reforms; for instance, the SA agricultural sector faces water scarcity, which will increase with climate change (Baleta & Pegram, 2014). Hence, the best use of rainwater and maintenance of land productivity is critical. CSATIs at farm level have the potential to address climate related challenges. However, inadequate technology adoption remains a challenge due to several barriers (Biazin *et al.*, 2012; Long *et al.*, 2016). These include lack of financial or human resources, institutional capacity, information, education and technologies among others (Asfaw & Lipper, 2016; Gandure *et al.*, 2013; Jack, 2009). Therefore, actions and strategies that enhance adoption and diffusion of CSATIs may be required. Consequently, knowledge of CSATIs, their characteristics and how these impact adoption is necessary.

Previous research focused on the impact of climate change on SA agriculture (Gbetibouo & Hassan, 2005; Maponya & Mpandeli, 2012a; Walker & Schulze, 2008), its sensitivity to climate change (Blignaut *et al.*, 2009) and to decreasing water resources (Schulze, 2011). However, knowledge gaps exist in relation to how socio-economic and other factors impact CSATIs adoption and diffusion in SA. A critical research area that will strengthen CSA research and practice includes an understanding of how socio-economic conditions interact with the technology characteristics. Exploring the characteristics of technologies is the first step to understanding their adoption puzzle, including if there are potential gaps in available technological innovations and to theorise potential challenges that different actors (e.g. farmers) may face.

The aim of this study is to:

- identify specific CSA technologies related to water use and management available in SA,
- to describe their characteristics,
- the context of their application and
- their potential to address climate change.

To achieve these objectives, this paper addresses the following research questions: What CSATIs are available in SA to address climate change related challenges? What are their characteristics and what is the context within which they are used? First, a literature review was conducted to provide an overview of the specific climate-related problems and risks in SA agriculture, CSATIs to deal with these challenges within SA context and various categories of classifying CSATIs. Based on the literature reviewed, categories for classification and characterisation of technological innovations are proposed. Subsequently, primary data was collected through semi-structured interviews with several groups of stakeholders such as governmental officials, researchers (including both from state-owned research institutions (e.g. WRC[3], ARC[4]) and selected universities), the private sector, farmer organisations and NGOs. They were asked to identify CSATIs with impact to water scarcity and drought caused by climate change.

2. Literature Review

2.1 Climate change risks and innovations to manage them in SA

Although, it is recently acknowledged that drought causes problems for all farmers, small scale farmers and subsistence farmers are most vulnerable (Maponya & Mpandeli, 2012a). An understanding of the risks and farmers' vulnerabilities is important to know if the technologies available are suitable (FAO, 2013). The risks facing African farmers include changing temperatures and rainfall patterns, increased drought and floods (Hellin *et al.*, 2012; Joshua *et al.*, 2014; Ziervogel *et al.*, 2010). In SA, the agricultural sector consumes about 65% of total available water (Blignaut *et al.*, 2009). This, together with the current socio-economic and

[3] Water Research Commission, see: www.wrc.org.za/
[4] Agricultural Research Council, see: www.arc.agric.za/

environmental context, signifies SA's vulnerability to climate change impacts (Ziervogel *et al.*, 2014). Consequently, water is conceivably the key medium through which early (and consequent) climate change impacts will be felt; hence the need to establish resilience to the projected impacts (Schulze, 2011).

Table 1 gives an overview of observed evidence of climate change (i.e. frequent and intense weather systems) and climate variability. Five (global) themes for categorising climate change and variability risks were identified. These themes were paired with specific climate change related risks in SA and innovations to reduce them, based on literature. These studies reflect the impacts of climate change which reduce access to water observed in the last two decades in SA. For instance, scenario projections for SA indicate reductions in summer rainfall ranging from 5%-10% in the eastern part of the country whilst marginal increases in early winter rainfall is projected for the western part (Biazin *et al.*, 2012; Blignaut *et al.*, 2009). Temperatures are expected to rise by between 2.3 ºC and 9.6 ºC, while precipitation will fall by 2% and 8% by 2100 (Benhin, 2008). Farmers have also perceived temperature increases and decline in rainfall (Bryan *et al.*, 2009). Recently, Mpandeli *et al.* (2015) concluded that Sekhukhune District in Limpopo Province, SA experienced droughts for several decades. To respond to these challenges, farmers employ a number of agricultural and technical activities in line with CSA principles, such as the adoption of drought tolerant seed varieties and crops that require less water such as maize and sorghum, direct seeding, rainwater harvesting and zero tillage system among others. Therefore, the links between climate change, drought and the specific CSATIs are key criteria in selecting and finding available technologies.

Table 1: Climate risk for farmers and innovation for risk mitigation in the South African Agricultural sector.

Global themes for climate change risks	**Climate change and variability related risk for farmers in SA**	**Innovations to reduce or manage risks**	**Sources**
Changes in average rainfall patterns, with some regions experiencing higher rainfall and others drying	Water scarcity caused by rainfall variability and excessive non-productive losses	Micro and Macro catchments rainwater harvesting *Insitu* rainwater harvesting	(Biazin *et al.*, 2012)
	Decrease in rainfall from the current level and seasonal shifts of rainfall	Drought tolerant crops to cope with declining rainfall Expansion of irrigation Water saving and harvesting technologies Changes in cropping patterns, planting dates and land under cultivation Conservation farming Livelihood diversification	(Mpandeli *et al.*, 2015) (Joshua *et al.*, 2014) (Ziervogel *et al.*, 2010) (Blignaut *et al.*, 2009) (Bryan *et al.*, 2009) (Schulze, 2011) (Gbetibouo & Hassan, 2005)
	Aridity	Rainwater harvesting	(Kahinda & Taigbenu, 2011)
	Precipitation will fall by 2% and 8%.	Improved farming technologies	(Benhin, 2008)

		Irrigation	
Increases in the average global temperature and heat waves	Increasing average temperature	Planting heat tolerant crops Livelihood diversification	(Joshua *et al.*, 2014) (Ziervogel *et al.*, 2010) (Gbetibouo & Hassan, 2005)
	Temperatures will rise by between 2.3 and 9.6	Heat tolerant crop varieties and animal breeds Supplemental feeds Crop residue cover	(Walker & Schulze, 2008)
More intense and longer droughts, particularly in the tropics and subtropics	Increased incidence of droughts and dry spells	Plant crops that require less water such as drought resistant and early maturing varieties Alter agronomic practices	(Mpandeli *et al.*, 2015) (Mpandeli, 2014) (Joshua *et al.*, 2014)
Increased frequency of heavy rainfall and extreme weather events over most land areas	Localised floods Periodic flooding Water runoff Soil evaporation Decreased/varying river flow	Basin technique Mulch technique Livelihood diversification	(Joshua *et al.*, 2014) (J. Botha *et al.*, 2007) (Mpandeli *et al.*, 2015)
Rises in the average global sea level	Sea level rise	Biological options (planting mangroves, estuary and wetland rehabilitation) Physical options (sea walls, barrages and barriers, raising infrastructure, water pumps).	(Joshua *et al.*, 2014) (Cartwright *et al.*, 2008)

2.3 Classification of technological innovations

Previously, innovations in agriculture have been noted for their role in industrialisation and recently for their potential to respond to climate change (Lybbert & Sumner, 2010; Pardey *et al.*, 2010). Rogers (1995) popularly defined innovation as an idea, practice or object that is perceived as new by an individual or other unit of adoption. Toborn and Harvesting (2011) remarked that innovation is a “deceptively simple term but in reality, it ranges from embodied external innovations (seed, fertilisers, pesticides, etc.) to systems changes building on agronomic and managerial innovations (conservation agriculture, rainwater harvesting, etc.)”. According to Toborn and Harvesting (2011), within the process of agricultural development, technology packages consist of various categories and simultaneous interventions of a non-technical nature, and therefore trying to understand them in isolation is unrealistic.

Many factors can influence technology adoption [see (Feder & Umali, 1993; Rogers, 2003; Sunding & Zilberman, 2001)]. These factors can be divided into three categories, namely; characteristics of technology, the farming environment into which the technology is introduced, and the farmer making the adoption decision (Morris *et al.*, 1999). Three major paradigms for explaining adoption decisions exist, namely: innovation-diffusion, economic constraint, and adopter perception (Adesina & Zinnah, 1993). Although all three paradigms are relevant, adopter perception is the least developed in the literature (Long *et al.*, 2016; Wandji *et al.*, 2012), warranting further exploration particularly to ascertain this aspect regarding CSA in SA.

Studies of farmers' perceptions in the context of adoption decisions regarding climate change (Adesina & Zinnah, 1993) have focused on problems such as soil erosion and land degradation. However, awareness about the problem needs to be balanced with knowledge about technological innovations designed to solve them. It is increasingly recognised that adoption alone, may not achieve optimal outcomes owing to mismatches between the technological design and the context within which they are used (Long *et al.*, 2016). Accordingly, farmers' perceptions of specific technology attributes are likely to condition their adoption decision (Assefa & Van den Berg, 2009; Mushunje *et al.*, 2011; Pannell *et al.*, 2006). Therefore, knowledge on the characteristics of the technologies will help us to explore their direct adoption, or drivers and barriers for adoption.

Technological innovations can be characterised and classified according to several parameters. Table 2 provides an overview of classifications for categorising the characteristics of technological innovations based on the reviewed literature [see (Toborn & Harvesting, 2011; Wandji *et al.*, 2012)]. The characterisation of technological innovations can be based on their state of development, novelty, complexity or the number of technical functions (Diederen *et al.*, 2002; Kaine *et al.*, 2008). For instance, a technology could either be mature or non-mature. When innovations first appear, potential users are hesitant regarding their effectiveness and are therefore inclined to view their use as experimental (Fernandez-Cornejo *et al.*, 1994).

Furthermore, criteria to classify technological innovations include considerations of their objectives (i.e. prevention, resource-saving) and the distinction between incremental versus radical innovations (Henderson & Clark, 1990). Technologies may also be categorised based on their ability to save resources such as land and labour. This is worth exploring, given the rapid population growth, land pressures (Adesina & Chianu, 2002) and diseases pressure (such as HIV, resulting in a shortage of labour) that are present in Africa. Hybrid seeds which increase yield and are drought tolerant may lessen expansion of land for yield maximisation and help to address water scarcity related to climate change. Technologies such as new seed varieties (within unchanged production systems) are considered incremental and others, like integrated pest management and agroforestry, involve radical change (Loevinsohn *et al.*, 2012). Since agricultural technologies usually address multiple, and at times conflicting objectives[5], it is necessary to balance the environmental objective of a technology with potential users' objectives, as the misfit could lead to non-adoption of these technologies.

Technological innovations generally imply some type of investment in cash, labour or learning and farmers are likely to invest when they expect economic benefits in return (Sin, 2012). New

[5] See http://dfid-agriculture-consultation.nri.org/summaries/dfidwp4.pdf

technologies have a drawback because they involve high costs for farmers, dis-incentivising adoption, notably when adequate finance is limited (Merrey *et al.*, 2006). For instance, initial investments in CSATIs such as macro-catchment rainwater harvesting systems and irrigation technologies may be unaffordable to poor farmers because of the costs of materials (Biazin *et al.*, 2012; Hellin *et al.*, 2012)

Besides technological attributes, the context in which technologies are being used (location), the people using them and how they are introduced by technology providers necessitate deliberation (Water, 2010). Locally generated technologies are likely to be compatible with farmers' current practices and more likely to be adopted (Morris *et al.*, 1999). Farmers with secure markets for their produce are more likely to invest in and innovate with new technologies (DFIDWP4, 2004; Merrey *et al.*, 2006). Another categorisation of CSATIs could be framed in terms of their ability to enable climate change adaptation or mitigation and their impact on farm productivity (IPCC, 2011).

Table 2: Criteria for classification and characterization of CSA technological innovations

Criteria to classify Technological Innovations (TIs)	**Relationship to adoption/ How the characterisation may impacts adoption**	**Sources**
Environmental objectives of TIs (i.e. prevention, resource savings,)	Misfit between environmental objectives and potential user (e.g. farmers) objectives could lead to non-adoption.	(Frondel *et al.*, 2007) (Sin, 2012)
Integrated or add-on	Add-on technologies are cost-effective relative to integrated technologies, which may require changing production practices.	(Henderson & Clark, 1990)
Incremental or radical	Incremental approach to technology adoption is likely to be preferred by farmers when uncertain about technology because it usually requires minor changes	(Anderson *et al.*, 2010) (Kaine *et al.*, 2008)
Adaptation versus mitigation	Balancing priorities will influence adoption decisions of farmers. Farmers in Africa are less likely to invest in emission reduction if there are few immediate benefits related to food or water security.	(SA, 2011) (Rojas *et al.*, 2014) (Neufeldt *et al.*, 2013)
State of development and novelty	Status of development of technology influences adoption. Immaturity impacts relative competitiveness of technology. Investments in new innovations higher risk than in mature technologies.	(Kaine *et al.*, 2008) (Diederen *et al.*, 2002)
Endogenous versus exogenous innovations	Technologies generated locally are likely to be compatible with current farming practices and thus stand a better chance of being adopted.	(Sonnino *et al.*, 2009) (Morris *et al.*, 1999)
Management-intensive (MI) versus capital-intensive (CI) technologies	Factors influencing adoption of capital purchases and management improvements tend to differ. Education and industry involvement tend to influence adoption of MI technologies in contrast to	(Zepeda, 1990)

	CI technologies which may appeal to producers of all education levels.	
Continuous versus discontinuous innovations	Facilitating diffusion of information, capacitating the farmers and their advisors may increase adoption. Switching costs to new technology depends on knowledge, skills and provisions required to make it work.	(Toborn & Harvesting, 2011) (Sin, 2012) (Diederen *et al.*, 2002) (Fischer *et al.*, 2015)
Innovations according to impact (new or improved quality products, increased yield, cost reduction) Areas of environmental impacts (e.g. water)	Cost reduction and environmental impact influence adoption decisions of farmers. Farmers with improved understanding of the environmental impacts of their technology choices are more probable to adopt environmentally friendly practices.	(Toborn & Harvesting, 2011) (Belin *et al.*, 2011) (Baumgart-Getz *et al.*, 2012) (Sin, 2012)
Labour and land saving innovations	Where labour and land are scarce, technologies requiring more of these resources are likely not to be adopted.	(Toborn & Harvesting, 2011) (Adesina & Chianu, 2002) (Merrey *et al.*, 2006)
Individual and collective innovations	The focus is on individual adopter and group of people for individual and collective innovations, respectively.	(Toborn & Harvesting, 2011)
Embodied, exogenous innovations (EEI) and packages of disembodied agronomic and managerial innovations (PDAMI).	Where technology is embodied in capital good such as seeds, fertiliser and pesticides, adoption may be improved as the manufacturer may provide finance or guarantee a loan for its purchase than with PDAMI such as conservation agriculture, rainwater harvesting.	(Morris *et al.*, 1999) (Sunding & Zilberman, 2001) (Toborn & Harvesting, 2011)
Low-cost versus high-cost technologies	In instances where technologies are deemed high-cost, adoption is likely to be low if farmers are not able to secure finances.	(Merrey *et al.*, 2006)
Technologies for household food security versus those for market production	Market-oriented production farmers are likely to adopt high-cost technologies relative to those aiming to achieve own food security.	(Merrey *et al.*, 2006)

3. Research Approach and Methods

3.1 Interview Data

Given that CSA is still being elaborated, in concept as well as in application (Campbell *et al.*, 2014; Mutamba & Mugoya, 2014), this study used an exploratory approach. To gather in-depth data on the CSA technologies promoted in SA and their characteristics and context of application, this research followed a qualitative research approach. The suitability of this approach is based on the research questions, which involved exploring the availability and characteristics of CSATIs in SA, through different expert viewpoints. Literature review and interview data were the main sources of evidence to discover the relevant themes related to the research questions. An interview protocol was developed using the literature review (see tables 1 and 2) and from discussions with knowledgeable key informants working in CSA in general and water management in particular. Considering the exploratory nature of this study, open-ended questions were posed for all interviews. The 43 questions contained in the protocol covered topics (as highlighted in table 2) needed to answer the research questions, and discussions held with key informants were conducted to confirm the validity and appropriateness of the protocol (see the appendix). These themes comprised questions under the following headings;

- Respondents (interviewee) background
- Institutional/Organisational perspective (about role, activities, initiatives of the organisations, and locations where CSA related initiatives are taking place).
- Existing and/or future expected water-related climate smart agricultural technologies (about characteristics of CSATIs, importance CSATIs to smallholder farmers).
- Key factors that could impact the adoption of CSATIs.

Data collection was conducted during February to September 2015. Primary data collection was conducted in two steps. First, discussions were held with knowledgeable key informants (n=5) to gain a general depiction of current issues concerning CSA in SA. We contacted two professors from the universities of Limpopo and North West, officials from Limpopo Department of Agriculture (LDA) and Agricultural Research Council, Institute of Soil, Climate and Water (ARC-ISCW) and FAO official based in SA. The discussions provided insights based on the respondents' views and experiences. We gathered useful information from university officials about CSA in SA, technologies and practices being promoted, government initiatives and efforts in promoting and implementing CSA. Next, officials from Limpopo Department of Agriculture, Agricultural Research Council, Institute of Soil, Climate and Water and FAO officials based in SA were contacted to triangulate information gathered from the professors and the literature. The discussions with key informants made clear that several relevant projects and interventions in which they are directly or indirectly involved were taking place.

Second, interviews were conducted with 27 CSA stakeholders in SA from various organisations using a standardised interview protocol (see Appendix B). Nonprobability purposive sampling (Palinkas *et al.*, 2015) was chosen, with referrals from existing contacts used to identify potential study respondents. Interview respondents had to be an employee of one of the organisations identified (through literature searches relevant to CSATIs or co-nomination) as relevant for CSA activities and initiatives, have or are working (in research or practice) in CSA in general and water management for agriculture in particular. Potential study respondents were contacted via email, telephone and invited to participate in the interview. Whilst questions of validity in qualitative research are not clear cut, the number of interviews conducted were felt to be sufficient for the research aims. This is because we achieved data saturation, since we reached a point were no new information was being acquired (Miles and Huberman 1994). Data gathered from our respondents was indicatively able to reflect and shed light on the available CSATIs in SA, their context of use and the factors affecting their adoption based on their knowledge, awareness and involvement in relation to CSA activities. Furthermore, our research sample included multiple perspectives (such as public sector, research institutes and universities) which allowed triangulation, thereby increasing the validity. Finally, as the research takes an exploratory and qualitative form the quality of the data is the most important factor See Appendix A for an outline of the respondents interviewed.

3.3 Data analysis

We followed several steps to make sense of the data from the interview transcripts. Firstly, we transcribed the data and during this process, we made memo's and noted key initial observations of the contextual information about details such as the project aims, the setting, participants and topic guides (protocol) that where relevant. This process is valued because transcribing is an interpretative act rather than simply a technical procedure, and the close observation that it entails can lead authors to noticing unanticipated phenomena. Secondly, data was organised and sorted by looking closely at what the respondents were doing concerning CSA and related projects, specific CSATIs being promoted and their opinions about them, the opportunities for enhancing and challenges hindering CSATIs adoption. We coded individual data items based on their relevance to the research questions. The coding process and categorisation were conducted using Atlas.ti. We used a word-based technique (Ryan & Weisner, 1996) to identify the relevant themes to answer our research questions. For a theme to be developed, at least 3 of the respondents had to note the factor. We repeated this process to maximise internal consistency within the categories and until most data items were positioned into the recognised categories. After sorting the different codes into potential themes, we revised the potential themes to see if they help to understand what the key factors to adoption of CSA in SA are.

For instance, R11 represented an official who manages about 28 agricultural water management projects, looking at the areas of climate change, agriculture and irrigation within the research institution which supports sustainable development through research funding, knowledge creation and generation. During the interview, he noted that water availability in certain areas of SA is a problem due to climatic variability and change. He further noted that the issue for farmers is to obtain good yield, irrespective of their farming system (i.e. dry or irrigated land). The respondent alluded that in the face of changing climate, there is a need to adopt strategies that are in line with CSA principles and mentioned that good examples in SA include Conservation Agriculture (CA), Rain Water Harvesting (RWH), Decision support tools and Drought-tolerant seeds. Whilst R11, R15 and R3 acknowledged the potential of various CSATIs, they were concerned about availability at village level and affordability of these technologies by the smallholder farmers. Some of the respondents noted that proof of benefits seemed to be a motivating factor, yet the benefits were not yet sensitised to most farmers. The coding process in this case started with identifying available CSATIs, their characteristics and factors likely to influence their adoption expressed by respondents. Therefore, the above excerpts were initially highlighted and then categorised based on commonalities or generalisations among various respondents. For example, respondents noted issues such as high price, lack of funds and availability of implements and we assigned them to the category of 'Availability and affordability of technology'. They also noted concerns that people must see the technology benefits, demonstrations and sensitisation of benefits are needed; and these were assigned to 'Proof of technology benefits' category. The description and characteristics of the available CSATIs in SA and key factors most likely to influence their adoption are elaborated in the results section.

4. Results of the interviews

4.1 Available CSA technologies in SA

During the interviews, CSA stakeholders in SA noted a set of technologies and practices consistent with CSA, which were promoted to respond to climate-related challenges facing farmers and the country. Table 3 highlights those technologies and practices. However, these are not ranked or ordered in terms of their importance, but are presented to briefly explain and highlight their availability and their associated CSA impact. For example, the results show that the adoption of seed varieties is expected to enable harvest even under adverse conditions, whilst helping farmers to deal with dry spells and mitigate against rain shortfall. However, no direct mitigation impact is expected from adoption of seed varieties.

Table 3: Description of the CSA technologies and practices based on interview data

CSA technologies and practices	Potential CSA impact
Seed varieties (drought tolerant and early maturing): Seeds developed to tolerate drought and mature early.	*Productivity/Incomes*: Enable harvest even under adverse conditions. *Adaptation*: Help farmers deal with dry spells and mitigate against rain shortfall. *Mitigation:* No impact.
Conservation Agriculture: A production system based on 3 principles namely; minimum or no tillage practice (minimum soil disturbance), permanent organic soil cover (consisting of a growing crop	*Productivity/Incomes*: Provide options for increased profits and improve food security. *Adaptation:* Avoid structural degradation. Crop rotation can fix nitrogen (which inhibits high

or dead mulch of crop residues) and diversified crop rotations.	prices of nutrients like fertilisers) and improve crop diversity. *Mitigation:* Less fuel from limited tractor use, and less GHGs. Safeguard carbon sequestration via carbon storage in the soil.
Rain Water Harvesting (RWH): Describe the range of techniques of concentrating, collecting, storing, and using rainwater runoff. Two types noted; In-field Rain Water Harvesting (IRWH) and Mechanised Basins	*Productivity/Incomes:* Increases rainwater productivity and yields. *Adaptation:* Helps to avoid risk of crop failure linked to erratic, declining rainfall and high run-off through efficient rainwater management. *Mitigation:* IRWH encompass No-till system, therefore, mitigation potential
Strip intercropping (SI): Practice of growing two or more crops together in strips wide enough to allow separate crop production using machines and close enough to permit crops interaction. Usually done with maize and leguminous crops for nitrogen fixation.	*Productivity/Incomes*: Increase productivity by maximising available land. *Adaptation:* Allow farmers to diversify, thereby improving food security and reducing risk of crop failure. *Mitigation:* No impact.
Biochar (B): A charcoal used as soil amendment. It is produced from plant matter and stored in the soil as a means of removing carbon dioxide from the atmosphere.	*Productivity/Incomes:* Potential to increase incomes of farmers in the presence of increasing temperature. *Adaptation:* Helps farms adapt to high evaporation from high temperatures by locking water in the soil. *Mitigation:* Reduces GHGs and enables sequestration since carbon is not lost through the atmosphere but locked in the Biochar.
Precision Irrigation Scheduling (PIS): Irrigates as and when water is required using sensor to detect moistures deficit.	*Productivity/Incomes:* Enables many production cycles per year, hence income security. *Adaptation:* This is a water efficiency technology which tackles water shortage. *Mitigation:* GHGs reduction possibility for those using generators.
Agroforestry (AG): Land use management in which harvestable trees or shrubs are grown among or around crops to maintain soil fertility and conserve moisture.	*Productivity/Incomes*: Improve soil fertility which can enable farmers to produce more yield *Adaptation*: Mitigates against soil infertility, erosion and conserve moisture. *Mitigation*: Provides potential for planting trees that can sequester carbon.

Site-specific nutrient management (SSNM): Focuses on application of nutrients (i.e. Nitrogen) to where is needed in farm during the time the crop needs it. Assessment of crop nutrients needs precede application.	*Productivity/Incomes:* Saves nutrients, so larger area can be treated with the nutrients at farmers' disposal *Adaptation:* Help farmers to spot place fertilisers, hence reduce evaporation and nutrients run-off. *Mitigation*: Fertilizer use reduction may result in reduced GHGs emissions.
Water Saving Irrigation Technology (WSIT): Underground irrigation. Feeds root system of crop by releasing water only when needed. Reduces evaporation and limit water run-off, implying less/no chemicals go on groundwater table.	*Productivity/Incomes*: Saves and make more water available for production. *Adaptation:* Help farmers to adapt to dry spells by reducing evaporation relatively higher than Subsurface Drip Irrigation. *Mitigation:* Little impact.
Drought Early Warning Detection (DEWD): A decision supporting tool (e.g. early warning system) for seasonal forecasts.	*Productivity/Incomes:* Reduce production losses linked to uninformed decisions. *Adaptation:* Help farmers to make informed decisions as they get the nature of cropping season before it starts. *Mitigation*: No impact.
Agro-ecology (AE): Type of farming system which does not rely on external inputs.	*Productivity/Incomes:* Encourage people to produce their own food. *Adaptation:* Help farmers to reduce food insecurity. *Mitigation:* No fertiliser application, an opportunity to reduce GHGs emissions.

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4.2 Key factors affecting adoption of CSA technologies and practices.

To expose the context within which the above technologies are used, respondents were asked what they considered to be key factors for adoption and what capacities smallholder farmers require to enhance adoption of the available technologies and practices. Respondents reported various factors likely to influence adoption of CSATIs in SA, which were developed into themes during the analysis (see section 3.3). To illustrate the different themes, respondent quotes are provided (in italics). The following key factors were highlighted by the data:

1. Awareness raising and provision of knowledge and skills: Respondents noted that farmers may not possess sufficient knowledge and skills required to make new technologies work. Additionally, farmers need to be made aware of where and how to access these technologies

Visibility on our side. We do have a license to sell hybrids. The farmers need to know where seeds can be found. (R2)

Farmers need to be empowered with skills and knowledge tailor-made to their needs, and in the language they understand. (R5)

2. Availability and affordability of technology: Respondents highlighted that unavailability and unaffordability of some technologies will affect their adoption, particularly by smallholder farmers. This theme comprised elements relating to the price of the technology and in some instances the fact that farmers lack financial resources to secure farming inputs. In other cases, however, the issue is on the supply side of the chain where promoted technologies were not yet on the market.

First is the price of technology. Second is the operational costs and maintenance. (R11)

Lack of funds, as seeds are not cheaper. (R15)

Implements are not always available, especially at village level for smallholder farmers. (R3)

The main thing is in terms of acquiring the seeds because so far, the seeds are not yet available in the market. (R27)

3. Farmers' attitudes, age and preferences: Respondents raised concerns about the aging farming population in SA. Older farmers are often reluctant to change their practices and this can be a hindering factor to technology adoption. Respondents further noted that besides improved yield, farmers may prefer other attributes such as seed colours and type; and these also need to be considered when technologies are promoted and introduced.

Other farmers still prefer traditional methods and are reluctant to change. (R15)

Ageing farmers are reluctant to adopt new technologies. (R6)

Proper introduction of technologies to farmers. Take care of farmers' preferences, for example, seed colours, type, and quality in addition to yield varieties. (R16)

You also have to deal with attitudes and mindsets, more especially of farmers. (R11)

Change is difficult. It is an issue of mindset. (R25)

4. Provision of support and complementary programmes: Provision of sufficient support, such as subsidy programmes, was mentioned as important for the adoption of CSA

technologies. However, a concern was raised that sometimes the government launches inharmonious programmes. Respondents stressed that the misunderstanding resulting from this may lead to non-adoption of CSA technologies, and therefore, suggest that CSA stakeholders need to coordinate their efforts and programmes to avoid confusing targeted farmers and unsolicited outcomes.

Lack of adequate support from government. Government advocates market-related practices and they would prefer GMOs over agro-ecology. (R19)

[...] Different viewpoints from stakeholders. Actors, government, and researchers don't speak the same language; there is a difference of opinions. For instance, other programmes such as mechanisation programs are still on, and push conventional implements parallel to the promotion of conservation agriculture (CA). (R3)

Currently, there is competition, we are just introducing CA, but farmers are still familiar with mechanisation (i.e. conventional farming). (R4)

5. Need for immediate benefits: Respondents noted that time frame of realising some benefits is likely to affect adoption of CSA technologies because often farmers are interested in immediate benefits.

[...] Farmers don't have patience...they require immediate benefits. (R13)

[...] I have realised that our farmers are only satisfied when they have yields that sustain them for one season, just for only family consumption. (R21)

6. Proof of technology benefits: The proof of technology benefits was notable as a motivating factor to adopt CSA technologies. This is related to factor 3 that farmers are usually reluctant, and therefore awareness raising activities should include a demonstration of direct benefits on farm level.

Proof of benefits, people must see the benefits. (R9)

Demonstration of benefits can serve a motivating factor. (R5)

Benefits of conservation agriculture are not sensitised to all farmers. It becomes difficult for a person to become baptised before they are born again. (R4)

Of course, we do awareness first and people will mostly check whether there are benefits. (R22)

7. Involvement of end users of the technologies: Moreover, respondents noted that failure to involve the end users (farmers) of technology during the development phase will lead

to non-adoption of CSA technologies. Hence, they suggested bottom-up approaches to technology development.

> *I think if you come up with technology and you have it all designed without involving farmers...it will be like you are imposing the technology to them. Do not impose technology on farmers. Use innovation platforms to engage farmers. (R20)*

> *Consultation with end-users of technologies prior to its development and introduction, bottom-up approach is vital. Respect culture and norms of communities. (R12)*

4.3 Reported characteristics of the CSA technologies

Following the identification of the CSA technological innovations (CSATIs) introduced and promoted in SA as well as key factors that impact their adoption, the next step was to explore further innovation variables. The innovation variables identified from the literature (see table 2) allowed an exploration of the characteristics of CSATIs promoted in SA. Table 4 provides a summary of characteristics of CSA technologies promoted in SA.

Table 4: Characteristics of the CSA technologies and practices as perceived by respondents in 2015

CSA technologies and practices (CSATIs)	Location and year which technology was first introduced	Management Intensive (MI)	Costs [(High (HC) or Low (LC)]	Effects on Labour	Return on Investment	Maintenance and operations
Conservation Agriculture	All 5 districts of Limpopo Province Since in 2000, in 2009 and again in 2011	Yes	Initial HC reducing overtime	Additional labour may be required	Gradual Benefits	Direct implication
Rainwater Harvesting	Sekhukhune, Vhembe and Waterberg, since 2007, in 2009	Yes	Initial HC reducing overtime	Additional labour may be required	Gradual Benefits	Direct implication
Agroforestry	Mopani, Vhembe, Waterberg and Capricorn, since 2013	Yes	Initial HC reducing overtime	Additional labour may be required	Gradual Benefits	Direct implication
Strip intercropping	Capricorn, Vhembe and Waterberg, since 2012	No	LC	Additional labour may be required	Immediate Benefits	No direct implication
Drought Early Warning Detection	Vhembe and Sekhukhune, since 2013	No	LC	Normal labour apply	Immediate Benefits	No direct implication
Site-specific nutrient management	Sekhukhune and Capricorn, since 2011	No	LC	Additional labour may be required	Immediate Benefits	No direct implication
Agro-ecology	Waterberg and Vhembe, since 2014	No	LC	Normal labour apply	Immediate Benefits	No direct implication
Seed varieties (drought tolerant and early maturing)	Vhembe, Sekhukhune, Capricorn and Waterberg, 2012, 2015 and ongoing	No	LC (mainly, OPVs)	Normal labour apply	Immediate Benefits	No direct implication
Biochar	Vhembe, since 2013	No	Initial HC reducing overtime	Normal labour apply	Immediate Benefits	No direct implication
Precision Irrigation Scheduling	Vhembe, since 2010	No	Initial HC reducing overtime	Normal labour apply	Immediate Benefits	Direct implication
Water Saving Irrigation Technology	Piloted in Gauteng Province only but the aim is to roll it out to other provinces plus Limpopo, since 2012	No	Initial HC reducing overtime	Normal labour apply	Immediate Benefits	Direct implication

Knowledge and skills required: All CSATIs were reported to be semi-continuous, demanding that farmers acquire additional knowledge and skills to make them work. Effects on land resources: All CSTIs noted were embraced and promoted for their potential to increase yield within the given land relative to their alternatives. OPVs= open pollinated varieties were noted to be relatively cheaper than hybrid varieties.

Respondents reported that all CSATIs are semi-continuous, requiring additional knowledge and skills to be imparted to farmers. All CSATIs were embraced and promoted for their potential to increase yield within the given land relative to their alternatives.

> *[...] If you want smallholder farmers to adopt technology, obviously you need to capacitate them and demonstrate to them that this technology could assist you to save water, etc. (R10)*

> *[...] Conservation agriculture also saves land as you use your land sustainably. More yields mean some land can be left to rest. (R25)*

> *[...] Of course, these seeds save the land ...If you plant something that is high yielding, with the same hectares of land, you produce more. (R24)*

Six CSATIs were considered to require high initial costs of investment. However, respondents noted that although the costs of these technologies are higher initially, they reduce over time. Out of 3 technologies which appeared important according to respondents, 2 (CA and RWH) were reported to be management intensive. Therefore, given the factors mentioned in subsection 4.2, this may imply that farmers lacking money to purchase equipment may not opt to adopt those technologies whilst ageing farmers may avoid management intensive technologies. All CSATIs except for Agroecology were reported to be land saving since they have the potential to increase yield with the same hectares of land relative to their alternatives. Although it was noted that normal labour will apply with most of the promoted CSATIs (7 out of 11), additional labour may be required to implement some. Regarding maintenance and operations, although 4 technologies were reported to have some implication, fundamentally, these technologies can be easily maintained and operated as farmers usually receive training. Other maintenance risks were reported not to be peculiar to CSA technologies.

> *With CA, the land equivalent ratio is better in smallholder farming. Total crop production is higher. Labour savings in commercial farming reduce tremendously but with smallholder farmers it depends. (3)*

> *The biggest problem with CA is actually management of weed. It is labour intensive but it reduces with time. I wouldn't say the same problem you are dealing with today with regard to CA would still be the same in 5 years' time. Of course, most of the things we are dealing with would be sorted over time. For example, weed will be suppressed over time. CA saves land because now you find the potential of your land as you build your soil structure, potential increases as well and you can produce more. (13)*

Another characteristic of the CSA technologies explored was the return on investment. Respondents reported that some technologies are associated with immediate benefits and some to be long-term, with benefits accruing in the future.

What we have seen is that significant impacts of CA are observable within on average 4-5 years. However, some changes can be seen in the first years. Nonetheless, hardly on the 1st year. (13)

RWH, if it is adopted by smallholder farmers, the return on investment is between 2-5 years. But that will depend on the geographical location where you are. (R11)

Benefits are immediate. You plant your seeds and then harvest the yield. (R16)

This exploratory study identifies available CSA technological innovations (CSATIs) in SA, their characteristics and key factors that may influence their adoption. Although respondents mentioned that all CSATIs were important, we looked closely at our data set and explored these technologies based on their characteristics. Therefore, based on the characteristics noted by the respondents Conservation Agriculture (CA), Rainwater Harvesting (RWH) and Seed Varieties that are Drought Tolerant and Early Maturing seem to be the most suited technologies and practices for the promotion of CSA in SA, particularly among smallholder farmers. These technologies were promoted as early as 2000, suggesting they have an ability to enhance resilient livelihoods of farmers in the face of changing climate. Table 4 provides a summary CSATIs promoted in SA, which gives an indication of the important technology for CSA in SA.

5. Discussion of the results

5.1 Implication of the characteristics and interplay factors that affect adoption

Respondents showed that SA smallholder farmers have been introduced to various CSATIs through a number of government programmes and private company interventions since 2000. However, these interventions do not always succeed in enhancing technology adoption by smallholder farmers due to several factors. Insights from respondents and literature were used as the basis for reflections regarding future challenges and opportunities for the adoption of CSATIs in smallholder farming and implications for future research.

Awareness raising, knowledge and skills provision were noted to be an important factor in influencing the adoption of CSATIs. These results concur with Diederen *et al.* (2002) who assert that knowledge and skills required to make a new technology work, determine switching costs and adoption rates. Respondents indicated that they created some level of awareness during the introduction and promotion of CSATIs to smallholder farmers. Methods to raise awareness include among others; workshops, farmers' field days and experimental demonstrations. These methods, however, are insufficient for transferring all the necessary information about the technology to farmers (Jacobson & Myhr, 2013). Furthermore, Eidt *et al.*

(2012), state that the effectiveness of sharing knowledge depends on how the knowledge is packaged. This could mean that alternative or additional methods (tailored to smallholder context) of transferring information about the technology are required and that information to farmers should be provided by multiple actors so that farmers are better able to judge the information given.

The second factor noted to impact on the possibility of CSATIs to be beneficial to smallholder farmers is availability and affordability. This is consistent with previous research (Long *et al.*, 2016; Merrey *et al.*, 2006; Sin, 2012), alluding that high costs involved with new technologies dis-incentivise farmers to adopt them. Respondents indicated that many of the technologies have been supplied to smallholder farmers through government-sponsored interventions (freely or greatly subsidised), and according to (Fischer *et al.*, 2015), this suggests that farmers have not yet experienced the real costs of these technologies. This could further explain the perceived behaviour of farmers to abandon technologies at the end of projects (interventions) noted by some of the respondents.

Past research also points towards the influence of farmers' attitudes, age and preferences on the adoption of technologies (Assefa & Van den Berg, 2009; Mushunje *et al.*, 2011). These concur with issues of ageing farmers and their attitudes towards new technologies and emerged as one of the key themes during the coding process. Another key factor identified by the respondents as crucial to influencing adoption of CSATIs is the proof of technology benefits. This is related to the factor on awareness because the process of sensitising these technologies can be coupled with the demonstration of benefits, particularly in farmers' fields where possible. Another justification for a demonstration of benefits at farm level as highlighted by (Fischer *et al.*, 2015) is related to the fact that smallholder farmers are operating in suboptimal agricultural environments which are likely to produce different outcomes.

Provision of support and complementary programmes was also noted to be strategic in influencing adoption of CSATIs in SA. This point tally's with Mnkeni and Mutengwa (2013) who noted that effective CSA implementation depends on clear policies and involvement of the necessary sectors. Hence, responsible organisations need to give due consideration to, and closely follow-up the newly introduced technology and the adoption practices of farmers (Assefa & Van den Berg, 2009; Eidt *et al.*, 2012). Respondents further indicated that contradicting (e.g. tractor subsidy versus promotion of no-till planters) rather than complementary government-funded programmes jeopardise the chance of adoption of CSA technologies. This suggests that conflicting programmes with respect to CSA, if not harmonised and properly targeted, could leave farmers confused, and is consistent with previous research (Mnkeni & Mutengwa, 2013).

Moreover, results of this study showed that benefits of the CSA technologies promoted in SA are not all immediate, reducing adoption. This assertion is analogous with Fischer *et al.* (2015) who indicated that smallholder farmers are not able to absorb the losses associated with the waiting periods before the benefits, due to their lack of an economic buffer. Furthermore, lack of appreciation of users' needs and wants by technology developers and providers highlighted by Long *et al.* (2016) was indeed noted by the respondents as an influencing factor to technology adoption. Respondents suggested that a more bottom-up approach towards technology development as opposed to imposing of technologies could to a great extent positively influence the adoption by farmers.

5.2 How innovation variables help us to understand the application of CSATIs in SA

Exploring the criteria highlighted through the literature allowed successful consideration of how CSATIs apply in the SA context and further permitted us to deliberate on possible strategies to improve the effectiveness of CSA promotion efforts in SA. For instance, respondents noted that unaffordability and unavailability of technological innovations will likely affect the adoption by farmers and based on table 3 this was expected as high-cost and capital intensive technologies were theorised to be unlikely adopted. Additionally, respondents noted the importance of raising awareness and providing knowledge and skills as a factor to adoption and this relates to characteristics of innovations such as continuous versus discontinuous present within the wider technological innovation adoption literature.

The misfit between the environmental objectives and potential user objectives theorised to affect adoption in table 2 was not mentioned explicitly by our respondents. However, the need for immediate benefits by farmers and involvement of end users of the technologies were noted, and this could imply that the objectives of farmers and goals of CSA need to be aligned to enhance adoption of CSATIs. Though, in general the variables identified in table 2 apply to agricultural contexts in SA and elsewhere, some respondents in our study noted that Agroforestry should be among prioritised CSATIs, yet literature shows that technologies like Agroforestry involve radical change (Loevinsohn *et al.*, 2012) which could mean they are less likely to be adopted as compared to incremental technologies like new seed varieties. Therefore, future research could explore under what conditions radical technological innovations would be most appropriate and perhaps what forms of support should accompany this approach.

5.3 Implication of the result for CSA efforts in SA

The results of the study highlighted that several CSATIs introduced and promoted in SA require high initial investments. The availability and affordability of technology, noted to influence technology adoption, suggests that efforts to promote CSA technology adoption in SA need to be carried out through local supply channels and at affordable prices. Seeing that all CSA technologies promoted in SA were found to be semi-continuous innovations, it is necessary that information channels on these innovations to smallholder farmers be increased and that flaws [see (Jacobson & Myhr, 2013; Mushunje *et al.*, 2011)] in how such information is transferred to them be avoided. For instance, CSA technology providers and extension officers could join forces through a holistic educational campaign to enhance levels of information with regards to CSA technologies. This approach could help in tailoring information transfer and ensuring that farmers receive and understand the required information.

Some CSA technologies promoted in SA currently are noted to be management intensive and requiring additional labour. Considering that most smallholder farmers are likely to be old farmers with physical weakness and lack of labour for manual weeding (Assefa & Van den Berg, 2009), it is fitting to target youth to enhance adoption of CSATIs in SA. A promising solution to these concerns is to invest in programmes that would encourage youth participation in agriculture as the country seeks to respond to climate change related challenges. Likewise, with regard to farmers' attitudes and preferences, the use of correct information dissemination channels regarding CSATIs could help in shaping smallholder farmers' perceptions to make informed decisions concerning the adoption of these technologies. For example, the creation of innovation platforms that are farmer-centred will give farmers a chance to learn and exchange knowledge with other stakeholders and their counterparts.

A conceivable alternative could be to engage smallholder farmers earlier in the innovation process to prioritise and support CSATIs that are more accustomed to their agro-ecologies and farming practices. This kind of approach, called user-centred innovation or co-creation, could have better prospects for enhancing adoption of CSATIs because it helps to overcome several barriers in adoption process [see (Long *et al.*, 2016)].

This study also identified gaps in knowledge that require further exploration to deepen our understanding of the CSA adoption puzzle in SA. This study primarily provided the context about CSATIs in SA and their characteristics as well as factors likely to influence their adoption. To gain further understanding, future research should seek to identify the barriers and drivers of CSA technology adoption from the perspectives of farmers and technology providers. This may reflect how farmers perceive [see (Long *et al.*, 2016; Mushunje *et al.*, 2011; Wandji *et al.*, 2012)]; for insights on the importance of perception) the barriers to the adoption of CSA technologies contrary or similarly to what the respondents of this study have said. This knowledge could assist other stakeholders to improve their offerings related and targeted to smallholder farmers in SA.

This study is the first and crucial step in understanding and answering the ‘what’, ‘how’ and ‘why questions related to the CSA adoption puzzle in SA. This study forms a good basis upon which to inform the nature and scope of further investigations. Whilst a wider representation of CSA could have been interviewed, we reached data saturation, highlighting that no new data existed. Although it is possible we have omitted some CSATIs, the research’s contribution is unaffected due to the broader application of the results towards the successful adoption of innovations for sustainability in agricultural contexts. Further research could reveal other CSA technologies that respondents in this study were not aware of, which farmers are practising and/or are promoted by other stakeholders in the country. Since results showed that awareness and access to information by farmers and how this information is transferred is crucial in advancing CSATIs adoption; further research could explore the effectiveness of different information dissemination channels used through government-funded programmes and/or private company interventions to transfer information on CSA technologies to farmers. It is likely that combinations of technologies may be needed to achieve better results with CSA efforts, so future research could investigate how this occurs in practice.

4. Concluding remarks

The study identified available CSATIs in SA and examined their characteristics and context of use, using an exploratory qualitative research approach. Data were collected by interviewing CSA stakeholders working in SA. The aim for taking this approach was to look at the adoption topic often observed through the lens of farmers, from a wider perspective of those who work in the field of CSA more generally and water management for agriculture. Several CSATIs promoted and introduced in SA were identified and characterised. Through the exploration of the available CSATIs, this study serves as an initial assessment towards understanding the context of CSATIs in SA. This is essential given that the agricultural sector in SA is faced with the dilemma of responding to climate change related challenges whilst increasing productivity of farmers.

Key results indicate that CA, RWH and Seed Varieties that are Drought Tolerant and Early Maturing seem to be the most suited technologies and practices for the promotion of CSA agriculture in SA. However, high initial investment costs and additional labour required as well as management intensiveness associated with CA and RWH may render these technologies disadvantageous in the SA context, especially for smallholder farmers. Drought Tolerant and

Early Maturing Seed Varieties, on the other hand, were noted to be less costly (particularly, OPVs), not management intensive and therefore may present better prospects of adoption, even by smallholder farmers. Results further indicate that awareness raising and effective transfer of information about the CSA technologies, provision of support and complementary programmes, demonstration of benefits and greater involvement of farmers as targeted users early in the innovations process is essential in enhancing CSATIs adoption. Moreover, the results suggest that a holistic educational campaign to enhance the level of information regarding CSA technologies whilst involving the farmers from the onset has the potential to enhance adoption of these technologies. This study further outlined key factors likely to influence adoption of CSATIs promoted in SA noted by respondents, and by relating these factors to the CSATIs' characteristics, implications of these results on the future research activities and policy actions towards improving the effectiveness of CSA promotion efforts in SA were deliberated.

3

Smallholder adoption of technology: evidence from the context of climate smart agriculture in South Africa

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CHAPTER 3

1. Introduction

1.1. Background

Climate change represents a serious threat to the agricultural sector, requiring resilience to climate impacts and reductions in greenhouse gas (GHG) emissions. Rural communities in Africa largely depend on rain-fed small-scale agriculture for their livelihood, and this makes them particularly vulnerable to changes in climate and climate variability (Nyasimi *et al.*, 2017; Rankoana, 2016; Zizinga *et al.*, 2017). While concerns regarding mitigation and adaption to climate change are renewing the momentum for investments in agricultural research and are emerging as added innovation priorities, it is expected that development and effective diffusion of new agricultural technologies and practices will influence how well farmers mitigate and adapt to climate change (Lybbert & Sumner, 2010).

The main challenge that agriculture faces concerning adaptation and mitigation is that more food will need to be produced, more efficiently, under highly unpredictable production conditions, with net reductions in GHG emissions from production and marketing. Hence, input use efficiency is necessary to keep up with these productivity demands and to compensate for the effects of climate change. Innovative approaches, which can be institutional or technological, will be an important response (Asayehegn *et al.*, 2017; Msangi *et al.*, 2012). A prominent approach is climate-smart agriculture (CSA), which attempts to sustainably increase agricultural productivity, food security and incomes through adaptation and enhancing resilience to climate change as well as by reducing GHG emissions (Arslan *et al.*, 2015; FAO, 2010, 2013). CSA can help to achieve the development goals of vulnerable populations who depend on agriculture (Partey *et al.*, 2018), but this will involve effective management of synergies and trade-offs between mitigation, adaptation and productivity goals.

South Africa, like many African countries, has been identified as being highly vulnerable to the impacts of climate change (Elum *et al.*, 2017). Although the country has a huge territory with a diverse range of climate, it is dominated by a semi-arid climate (Chami & Moujabber, 2016). The South African agricultural sector's specific climate change impacts include moisture stress, climate variability, drought, scarce rain, erratic rainfall, depletion of water resources, excessive heat, soil erosion, and barrenness, which negatively impact agricultural production (Chami & Moujabber, 2016; Mpandeli *et al.*, 2015; Rankoana, 2016). These impacts are changing the functioning of the agricultural landscapes in devastating and often destructive ways. South African farmers are expected to adapt their agricultural practices to build their adaptive capacity and boost their resilience. CSA targets both crop and livestock production and can include conservation agriculture, soil and land management practices, use of new crop varieties and animal breeds, rainwater harvesting, agroforestry, mixed cropping, crop type diversification, adaptation to changing soils structure (Below *et al.*, 2010; Mpandeli *et al.*, 2015; Rankoana, 2016; Ubisi *et al.*, 2017). Given the evidence that climate-related challenges demand modification to agricultural practices, the transition to CSA necessitates farmers' access to productivity-enhancing and climate-smart technologies (Mutamba & Mugoya, 2014). This is especially true for smallholder farmers who are predominantly exposed to climate change (Grainger-Jones, 2011; Zizinga *et al.*, 2017).

Technological innovations and improved farming practices that increase productivity while boosting climate resilience present in South Africa include drought-tolerant seed varieties, drip irrigation, and the precision of application of fertilizers and agrochemicals, as well as practices such as integrated pest management, conservation farming, and improved watershed and soil management, among others (Senyolo *et al.*, 2018; Weisenfeld & Wetterberg, 2015). The challenge however is, to get these technologies into the hands of the farmers who need them (Nyasimi *et al.*, 2017; Weisenfeld & Wetterberg, 2015). Thus, while CSA technologies have been promoted for their potential to help farmers mitigate climate change impacts, effective adoption and use within the smallholder community is not a straightforward exercise.

Despite the evidence that where there is effective uptake of CSA practices and initiatives, the agricultural sector has become more adaptive and resilient to climate variability and farmers got protection against changing weather patterns, pests and diseases (Suleman, 2017; Wekesa *et al.*, 2018), smallholder farmers adoption is insufficient (Barnard *et al.*, 2015). Technology adoption and specifically the transition to CSA is affected by several factors (Baiyegunhi, 2015; Fischer *et al.*, 2015; Long *et al.*, 2016; Meijer *et al.*, 2015; Mushunje *et al.*, 2011; Nyasimi *et al.*, 2017; Senyolo *et al.*, 2018). These include barriers related to capital and high costs of labour, availability of inputs, uncertainty, cost and benefits of the technology, gender, socio-cultural practices, access to market, access to credits and lack of knowledge among others, and the fact that some CSA measures often reduce short-term profits (Drechsel *et al.*, 2005b; Fischer *et al.*, 2015; Mulaudzi & Oyekale, 2015; Nyasimi *et al.*, 2017). Failures to take specific contexts and the perception of farmers into account during technology development and application is also a contributing factor (Long *et al.*, 2016; Senyolo *et al.*, 2018). Interventions are often required to encourage technology adoption. Slower adoption rates result in loss of potential benefits of sustainable practices to farmers and the public (Ghane *et al.*, 2011). The perceptions and attitudes of farmers are highlighted as important in previous research (Drechsel *et al.*, 2005b; Fischer *et al.*, 2015; Mekoya *et al.*, 2008; Nyasimi *et al.*, 2017; Zubair & Garforth, 2006), however, they are not adequately addressed and understood (Meijer *et al.*, 2015).

Previous research has explored farmers' perceptions of climate change, evaluated CSA technologies and practices, explored demographic use patterns, and agronomic, economic and environmental benefits of the technologies (Baiyegunhi, 2015; Fischer *et al.*, 2015; Gandure *et al.*, 2013; Mulaudzi & Oyekale, 2015; Mutamba & Mugoya, 2014; Rankoana, 2016). Considering that farmers' socio-economic conditions and perceptions of technology affect adoption decisions (Bryan *et al.*, 2009; Deressa *et al.*, 2009; Drechsel *et al.*, 2005b; Tessema *et al.*, 2013; Ubisi *et al.*, 2017), we seek to analyse the role of these factors within the context of CSA technologies in smallholder settings. For instance, factors such as poverty, income, education, or investment costs, may limit the widespread implementation of CSA (Harvey *et al.*, 2014).

This study focuses on drought-tolerant seed varieties (DTSVs) for maize as a CSA technology relevant for smallholder farmers in rain-fed crop production (Asayehegn *et al.*, 2017; Senyolo *et al.*, 2018). In sub-Saharan Africa in general and in SA in particular, maize is the critical crop due to its importance to food security and economic wellbeing. However, the production of this crop by smallholder farmers largely relies on rainfall, which is increasingly erratic (Fischer *et al.*, 2015). Unreliable rainfall accompanied by frequent droughts, make it difficult for smallholder farmers to obtain high crop yields and, therefore, susceptible to food insecurity (Mdungela *et al.*, 2017; Mpandeli *et al.*, 2015).

This chapter aims to better understand smallholder decision-making about DTSVs as an example of CSA technology, in order to pinpoint how opportunities might be created to assist farmers in implementing CSA. The results highlight the value of considering the context-specific biophysical factors, socio-economic realities and perceived characteristics of innovations, knowledge, attitudes, and perceptions of farmers when exploring CSA implementation in SA.

This chapter contributes to an increased understanding of smallholder farmers' CSA technology adoption in developing countries by shedding light on the specific socio-economic and socio-technical variables that are important for promoting CSA in SA. The socio-economic and socio-technical variables are important and may improve our understanding of the disparity between perspectives of users (e.g. farmers) and developers as well as promoters of CSA technologies and practices [see (Harvey *et al.*, 2014; Meijer *et al.*, 2015)]. Understanding what drives or hinders adoption of promoted CSA technologies among smallholder farmers in SA may assist in targeting existing CSA technologies or redesigning them to suit the preferences and specific situations of farmers to safeguard adoption and sustainability.

1.2 Context for CSA technologies perception and adoption

Despite the benefits of CSA technologies (Elum *et al.*, 2017; Khatri-Chhetri *et al.*, 2017; Khatri-Chhetri *et al.*, 2016), adoption by farmers can be fairly low as numerous factors influence the extent to which farmers adopt CSA technologies (Khatri-Chhetri *et al.*, 2017; K Palanisami *et al.*, 2015). While technological adaptations may benefit from the literature on agricultural technology adoption (Tessema, 2018), understanding the adoption process of specific CSA technology (DTSVs in this case) is necessary to ascertain if the determinants of adoption are similar or unique in the face of changing climate. In agriculture, adoption processes take place amid specific policy, social and cultural, climate, geographical, technological, and economic contexts (N. Botha & Atkins, 2005; Falaki *et al.*, 2013; Mackrell *et al.*, 2009). Therefore, considering that technology uptake is a multifaceted process, shaped by many factors. Consequently, the exploration to understand diffusion and utilisation of agricultural technologies cannot be limited to just understanding the characteristics of adopters, their biophysical contextual factors or information sources. The adopter's perceptions of climate change and/or technologies or practices to address them is also needed to provide a comprehensive picture for analysing decision making (Jiri *et al.*, 2015; Meijer *et al.*, 2015; Mushunje *et al.*, 2011; Pannell *et al.*, 2006; Rankoana, 2016; Ubisi *et al.*, 2017). For instance, a comprehensive framework comprising the extrinsic (e.g. characteristics of adopter and innovations) and intrinsic (knowledge, perceptions, and attitudes) variables may increase our understanding of the complex process of adoption (Meijer *et al.*, 2015). Accordingly, exploring the contribution of socio-psychological factors such as perceptions of farmers regarding the specific attributes of CSA technologies in addition to the highlighted socio-economic factors could contribute to our understanding and on-going discussion about CSA adoption. In the following subsections, we continue to explain specific sets of factors in greater detail. Figure 1 shows the conceptual model. We assume that adoption decisions are conditioned by the socio-economic realities of the farmer, the characteristics of the external environment (or contextual factors), as well as the perceived characteristics of CSA technologies.

1.2.1. Influences of agricultural technology adoption decisions

Various technology adoption studies conducted in developing countries (Adesina & Chianu, 2002; Akinola *et al.*, 2010; Doss, 2006; Feder & Umali, 1993), indicate that the importance of factors affecting technology adoption vary across countries and regions owing to differences in natural resources, political and cultural ideologies, and socio-economic realities. Moreover, determinants of adoption of agricultural technologies can be grouped in several ways (Mwangi & Kariuki, 2015). Categories include technology and location, among others (Bonabana-Wabbi, 2002). In this study, we investigated the factors determining adoption of CSA technologies by exploring not only the farmers' socio-economic realities and characteristics of external environment (i.e. contextual factors). We have also considered additional factors extracted from farmers' perceptions of CSA technology-specific attributes as well as the role of communication and extension.

1.2.2. *Effects of familiarity with technologies and perceived technology attributes on adoption decisions*

The role of familiarity, which can come as result of education, awareness creation, training, and demonstration in the adoption process, is widely recognized (Deressa *et al.*, 2009; Meijer *et al.*, 2015; Mushunje *et al.*, 2011; Ubisi *et al.*, 2017). Generally, people's familiarity and understanding of technologies underlie their knowledge, perceptions, and attitudes towards them. Furthermore, innovation characteristics that influence adoption include relative advantage, observability, trialability, compatibility and complexity (Adesina & Zinnah, 1993; Ghane *et al.*, 2011; Mwangi & Kariuki, 2015; Rogers, 2003). Innovations, which are perceived as having a superior relative advantage, observability, compatibility, trialability, and less complexity, will have a better rate of adoption than other innovations (Rogers, 2003). These attributes can be elaborated as follows: (1) relative advantage refers to the perceived net benefits when individuals adopt. (2) Trialability refers to how easy it is to move from non-adoption to adoption through learning (Pannell et al., 2006). (3) Compatibility refers to the extent to which an innovation is attuned to current norms and practices and (4), complexity, measures the effort required to understand and use the new innovation (Mannan & Nordin, 2014). For instance, farmers find a technology to be a positive investment if they perceive it to be consistent with their needs and compatible to their environment (Mignouna *et al.*, 2011). Lastly, (5) observability of the technology, describes the extent to which results of an innovation are visible to others. Thus, the more advantage witnessed, the easier the diffusion. The following subsections will indicate the role of farmers' socio-economic realities and the external environment on the likelihood of CSA technology adoption decisions.

1.2.3. *Effects of farmers' socio-economic realities on adoption decisions*

Specific characteristics (gender, age, marital status), economic variables (income, assets, education) and networks (farmer organisations) affect adoption directly and indirectly by influencing the knowledge, familiarity with technologies, and perceptions of farmers. This in turn influences their decision to adopt certain technologies in relation to others or not to adopt (Kariyasa & Dewi, 2013; Meijer et al., 2015; Mushunje et al., 2011; Mwangi & Kariuki, 2015; Pannell et al., 2006; Wanigasundera & Alahakoon, 2014).

1.2.4. *Effects of external environment on adoption decisions*

In smallholder farming, other external forces such as information on new and alternative technologies, political conditions, geographical settings and ecological conditions, also have influence on technology adoption decisions and processes (Asayehegn *et al.*, 2017; Meijer *et al.*, 2015). For example, climate variability and change may increase the frequency and intensity of drought, and consequently influence the innovation to adapt to changes (Asayehegn *et al.*, 2017; Chami & Moujabber, 2016; Mpandeli *et al.*, 2015). Accordingly, farmers tend to embark on several agricultural and technical activities, such as adjustment of fertilizer input, adoption of drought-tolerant varieties and plant crops that require less water, during drought periods (Mpandeli *et al.*, 2015). Governmental support and the political will to introduce technologies and biotechnology for smallholder farmers is understood to be crucial for the success of interventions aimed at enhancing smallholder farmers' adoption of biotechnology and climate change adaptation practices, for instance (Edge *et al.*, 2018; Zizinga *et al.*, 2017). In general, smallholder farmers in Africa rely on extension services, usually provided by government. Poorly performing extension services are often blamed for the limited uptake of technologies. According to Drechsel *et al.* (2005), knowledge about the technology can be shared by means of communication infrastructure, media access and networks of continuously updated extension agents. As previous studies alluded to the role of communication and extension in influencing adoption (Meijer *et al.*, 2015; Pannell *et al.*, 2006), it was worth exploring to see if these factors also hold when considering the transition to CSA technologies.

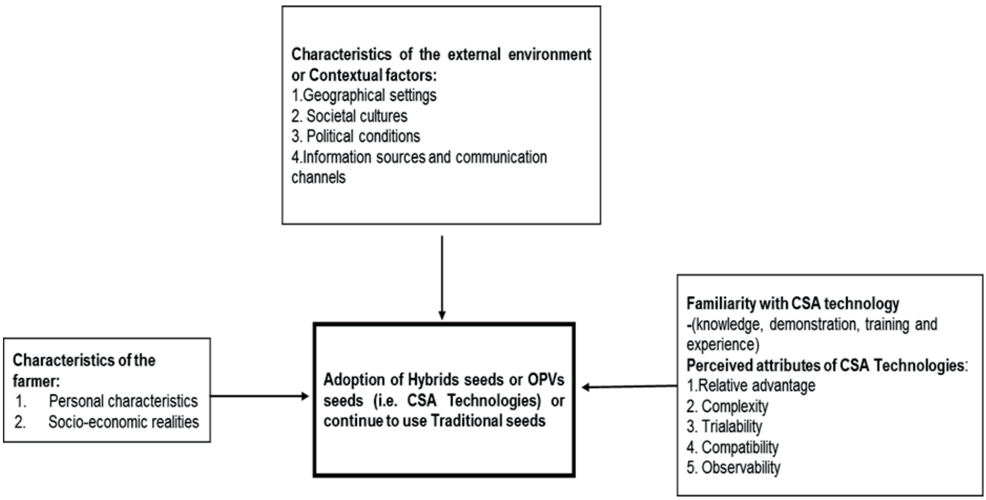

Figure 1: Conceptual framework reflecting factors affecting adoption of CSA technologies (i.e. DTSVs)

2. Materials and methods

The study in this chapter was explored through a survey approach. See page 16 and 17 of the general introduction for details concerning study, data collection and management employed in this study.

Table 1: Elaboration of how sampled farmers were selected

Districts **Total number of accessed smallholder farmers**	**Probability proportional to sample size per district**	**Total smallholder farmers interviewed**
Vhembe (198 smallholder farmers, 42% of 475)	42%	87
Capricorn (182 smallholder farmers, 38% of 475	38%	71
Sekhukhune (95 smallholder farmers, 20% of 475)	20%	38
Total sampled smallholder farmers (41% of the sampling frame of 475)		**196**

The socio-economic characteristics data were analysed using descriptive statistics. Factor analysis (FA) described the covariance relationships among many variables in terms of a few underlying, but unobservable, random quantities called factors and interpreted through weights of the variable called factor loadings, organized in a matrix (Hair *et al.*, 1995). FA seeks to reduce a large set of measured variables in terms of relatively few new dimensions known as factors with the aim of condensing all the information from the original interdependent variables to a smaller set of independent variables [see (Mugi-Ngenga *et al.*, 2016)]. The FA model is organized in such a way that all variables within each factor are highly correlated among themselves but have relatively small correlations with variables in other factors (Chaminuka *et al.*, 2008). Usually, factors used for further analysis should contain unique variables. In this study, nine factors were retained for subsequent analyses.

The significance of the factors that influence adoption of CSA technologies by farmers was analysed using Multinomial Logistic Regression (MNLR) Model. For the estimation of the MNLR model, one category (i.e. base category/the reference) was normalized as being the last category (traditional seeds) and therefore all results were explained in reference to this category. This was with respect to the use of seeds. These analyses were conducted using SPSS version 24.

2.3. Description of variables in the Multinomial Logistic Regression Model

Farmers were asked questions on their socio-economic realities and the description and measurement of those variables is presented in table 2. Data were also collected on the perception of farmers on specific attributes of CSA technologies (i.e. DTSVs in this case). The perception statements were measured on a 5 point Likert scale. The Likert scale ranged from one 'strongly disagreed' to five 'strongly disagreed'.

Table 2: Description of variables in the Multinomial Logistic Regression Model

Variable	**Description**
Gender	1= male, 0 otherwise
Age	1= elderly, 0 otherwise
Marital status	1= married 0 otherwise
Household size	1= 2 to 6 members, 0 otherwise
Farming experience	1= 17 years and above , 0 otherwise
Education	1= formal schooling, 0 otherwise
Reason for farming	1= farming for consumption and marketing, 0 otherwise
Income level	1= middle income (115.4-269.2), 0 otherwise
Land size	1= 0.25 ha - 2.7 ha, 0 otherwise
Government support	1= received government support, 0 otherwise
Credit access	1= credit access, 0 otherwise
Cooperative membership	1= member of cooperative, 0 otherwise

3. Results and Discussion

3.1. Socioeconomic characteristics of surveyed farmers in Limpopo Province, South Africa:

The socio-economic variables of the respondents, potentially impacting the adoption of CSA technologies are presented in table 3. For instance, data shows that sixty-eight percent of the respondents were female while only 32% were male. The average age of the interviewed farmers is 55.15 years old, and the youth accounted for only 11% of the respondents. Regarding education, 90% of the respondents obtained formal education and only 10% have not been to school. More than 80% of the farmers are married. Sixty-five percent of the farmers noted consumption and marketing as their main reason for engaging in agriculture. Socio-economic factors are usually more influential to the dissemination of a technology than biophysical factors (Drechsel *et al.*, 2005b; Senyolo *et al.*, 2018). According to Drechsel *et al.* (2005b), the biophysical conditions are often well described in common manuals, making them relatively easier to verify, yet with the social, cultural and economic perspectives, the situation is complex.

While access to government support (i.e. formal extension services) usually influence adoption of technologies positively (Diale, 2011; Ikheloa *et al.*, 2013), this was not the case in our study. Our data shows negative relationship between government support and the use of DTSVs. During discussions with farmers, concerns regarding extension services such as un-coordinated services, and lack of adequate monitoring and evaluation were raised. Only 34% of the farmers belonged to cooperatives. Farmers' concerns regarding extension support may have attributed to the often-observed biases in service provision towards farmers belonging to agricultural primary cooperatives. Since the issue of climate change has assumed an important position in public discourse and media we asked respondents if they think they experienced climate change. Almost all of them (195) noted they have experienced it. Previous studies indicated the relationship between technology adoption (also in response to climate change) and access to land (Diale, 2011; Ikheloa *et al.*, 2013). The average land size that interviewed farmers had access to was 1.89 hectares, with majority of the respondents having access to between 0.25 ha and 2.7 ha of land. In line with past research, a positive relationship between farm size and technology adoption was expected but negative statistical significance was observed (Mulaudzi & Oyekale, 2015). From the data of this study a positive and negative insignificant relation was observed between access to land and the use of "Hybrids and Hybrids with OPVs or Traditional seeds" and the use of "OPVs and OPVs with traditional seeds", respectively. Sixty-nine percent of the respondents came from the family of about 6 to 8 members, with an average household size of 6 (5.58) members. The mean farming experience for the farmers was 17 (i.e. 16.68) years.

Table 3: Socio-economic characteristics of the respondents

Characteristics	Frequency	Mean	Percentage	Min	Max
Male	62		31.6		
Female	134		68.4		
Age (years)		55.15		25	84
Married	159		81.1		
Never married	37		18.9		
No schooling	20		10.2		
Attended school	176		89.8		
Produce for family consumption	68		34.7		
Produce for family consumption and marketing	128		65.3		
Household size		5.58		2	9
Farming experience		16.68		3	35
Land size		1.89		0.25	17
Title deed	10		5.1		
Permission to Occupy (PTO)	185		94.4		
Neither Title deed nor PTO	1		0.5		
Experienced Climate Change: Yes	195		99.5		
Experienced Climate Change: No	1		0.5		
Government support	150		76.5		
No Government support	146		23.5		
Cooperative membership	67		34.2		
Not Cooperative membership	129		65.8		
Access to credit	88		44.9		
No Access to credit	108		55.1		

Sources of credit: Formal institutions (3%); Stockvel or Saving group (18%); Loan Shack ('Matshonisa') (7%); Other sources (66%) and More than one sources (6%)

1.2. Types of CSA technologies (i.e. DTSVs) used by the respondents

Previous studies indicated that the availability and affordability of technologies potentially affect their adoption (Diale, 2011; Senyolo *et al.*, 2018). Where crop farming is the main land-use option and more so in the face of changing climate, seed materials are often crucial. Farmers were asked about the seed varieties they used and their procurement processes. Table 4 indicates that 69.4% of the farmers used Hybrids and Hybrids with OPVs or traditional seeds. Twelve percent of the respondents reported using OPVs and OPVs with traditional seeds, while 18% were using traditional seeds only. Specific reasons were provided by farmers who reported using more than one seed variety in one season, within one field. For instance, farmers noted that unavailability of the OPVs, unaffordability of the Hybrid seeds, and provision of the seeds by the government and/or research institutions influenced their choice of seeds. Moreover, some respondents indicated that Hybrid seeds gave relatively higher yields, justifying their expense, while others argued that recycling traditional seeds were preferred in ensuring household food security.

Table 4: Types and sources of seeds

Variable	Frequency	Percentage
Types of seeds		
Hybrids and Hybrids with Open Pollinated Varieties (OPVs) or Traditional seeds	136	69.4
OPVs and OPVs with Traditional seeds	24	12.2
Traditional seeds	36	18.4
Sources of seeds		
Self-purchased	50	25.5
Government seed provision scheme (i.e. LDA)	28	14.3
Saved from farm	21	10.7
Other sources and/or combination	97	49.5

In response to unaffordability and unavailability, some farmers resorted to using traditional seeds and/or combination of seeds at their disposal. Twenty-six percent of the farmers purchased their own seeds and 50% acquired their seeds through a combination of channels. Although the South African government has attempted to assist farmers through different inputs provision programmes, this still seems inadequate as only 14% usually attained seeds from government seed provision schemes. However, it should be noted that among the 97 farmers who obtained seed materials from a combination of sources, there were those that received seeds from the government. In these cases, challenges, other than access, existed (i.e. lack of monitoring of service providers, lack of planning resulting in late delivery of inputs, small quantities of seeds & fertilizers).

The previous subsection has provided an overview of farmers' socio-economic conditions that were expected to affect farmers' adoption of CSA technologies to safeguard food security in the face of climate change. The following section tests the significance of the socio-economic characteristics that are theorised to impact the perceptions of the CSA technologies specific attributes; and to test the significance of the theorised variables in driving or hindering farmers' adoption of CSA technologies. Factor analysis (FA) and a Multinomial logistic regression (MNLR) model were used for empirical analysis.

1.3. Farmers' perceptions of the CSA technology specific characteristics

Farmer's individual perception of a given challenge may influence their decision towards possible solutions (Drechsel *et al.*, 2005b). Limpopo farmers have preferences for certain CSA technologies, based on real experience or perceived characteristics. Therefore, several questions were asked to understand this aspect. Farmers' perceptions of the CSA technology attributes were measured by respondents' opinions about the characteristics and important effects of CSA technologies in their area. This was based on Kaizer-Meyer-Olkin (KMO) Measure of Sampling Adequacy (KMO=0.80), similar to (Bidogeza *et al.*, 2009; Mugi-Ngenga *et al.*, 2016).

Table 5: Rotated component matrix[a] for farmers' perception of CSA Technology specific characteristics

Farmers' perceptions of the CSA Technology Attributes	Component/factor				
	1	2	3	4	5
I have adequate training on planting drought tolerant and fast maturing cultivars DTSVs	**.820**	.308	-.176	-.098	.214
I currently have adequate opportunities for training related to (DTSVs)	**.855**	.164	-.226	.005	.223
DTSVs have been well demonstrated in my area	**.713**	.271	.109	-.250	-.002
I have adequate access to agricultural advisory services regarding DTSVs	**.813**	.074	-.040	-.014	.157
I have knowledge about DTSVs	.295	**.755**	-.141	-.082	.214
I have knowledge on better planting date for DTSVs	.270	**.746**	-.078	-.130	.236
Planting DTSVs enable extra yield to be realized	.181	**.720**	-.092	.090	.177
Planting DTSVs safeguard household food security	-.167	**.739**	.046	.186	-.177
Planting DTSVs offers immediate benefits	.052	**.513**	.225	.074	-.232
It is important to be informed about weather information in my area	-.174	-.039	.000	**.758**	.015
It is important to know about better planting date for DTSVs	-.104	-.019	-.039	**.842**	.058
It is important to receive tractor services in time to plant DTSVs	.022	.052	-.075	**.791**	-.077
I have knowledge of non-agricultural activities that could sustain my life better	-.036	.054	**.882**	-.129	-.091
I consider knowledge about other activities other than agriculture important	-.027	.093	**.819**	.127	-.241
I can switch from agricultural production to exercise other activities if am informed about them	-.078	-.118	**.564**	-.158	-.001
I have a relevant expertise and/or experience to get the job elsewhere	-.100	.054	**.862**	.065	-.201
Additional training would increase my ability to adopt DTSVs	.242	.066	-.163	.018	**.722**
Information about other CSA technologies would increase my ability to adopt them	.173	.078	-.188	.054	**.811**
I consider knowledge about other CSA technologies and practices important	.078	.122	-.070	.445	**.526**
% of total variance	**23.7**	**14.8**	**12.2**	**7.2**	**5.1**
Eigen values	**4.98**	**3.11**	**2.56**	**1.51**	**1.06**
Cronbach's alpha	**.876**	**.760**	**.826**	**.754**	**.663**

Extraction Method: Principal Component Analysis: Varimax with Kaizer Normalization; Kaizer-Meyer-Olkin Measure of Sampling Adequacy (0.80, Chi-square =1894.97); Cut point for loadings and communalities = 0.5.

Table 6: Parameter estimates: “Traditional seeds” as Reference Category

Independent Variables	**Hybrids and Hybrids with OPVs or Traditional seeds**			**OPVs and OPVs with Traditional seeds**		
	B	**Std. Error**	**Exp (B)**	**B**	**Std. Error**	**Exp (B)**
Intercept	-14.848	1444	(.992)	2.681	1.748	(.125)
Training and demonstration related to DTSVs	.786	.336	2.195 **(.019)****	.735	.386	2.085 **(.057)***
Knowledge possession and benefits related to DTSVs	1.091	.279	2.977 **(.000)*****	.761	.343	2.140 **(.027)****
Knowledge on non-agricultural activities	.156	.337	1.169 (.677)	.018	.427	1.019 (.965)
Necessary requirements	.803	.475	.448 **(.091)***	-.029	.623	.972 (.963)
Enabling factors	.961	.302	2.613 **(.001)*****	.770	.378	2.160 **(.041)****
Gender	-1.020	.602	.361 **(.090)***	-.626	.758	.535 (.409)
Age	1.171	.784	3.226 (.135)	-.495	.944	.610 (.600)
Marital status	-1.791	.775	.167 **(.021)****	-1.312	.980	.269 (.181)
Household size	-.112	.640	.894 (.862)	-.018	.932	.982 (.984)
Farming experience	-.685	.739	.504 (.354)	.058	.921	1.060 (.950)
Education	-.407	.997	.665 (.683)	-1.274	1.468	.280 (.385)
Income: middle (115.4-269.2)[a]	.292	.650	1.339 (.653)	.224	.817	1.251 (.784)
Income: high (higher than 269.2$)	.871	1.074	2.390 (.417)	1.404	1.400	4.070 (.316)
Reason for farming	-.195	.598	.823 (.745)	-1.003	.775	.367 (.196)
Land size: 0.27ha to 2.7ha	16.998	1444	2410 (.991)	-.986	.982	.373 (.315)
Land size: 3.0 ha to 6.0	16.533	1444	1514 (.653)	-1.340	.000	.262(-)
Credit access	1.129	.558	3.094 **(.043)****	-.466	.711	.627 (.512)
Government support	-.613	.642	.542 (.340)	-.190	.867	.827 (.826)
Cooperative membership	-.185	.671	.831 (.782)	-1.171	.828	.310 (.157)

Reference category **Traditional seeds**
Number of observations **196**
Based on exchange rate of 1$ =13ZAR

Note: *, ** and * are significant levels at 1%, 5 % and 10% respectively**
OPVs= Open Pollinated varieties, DTSVs=Drought tolerant seed varieties

Table 5 shows the rotated factor farmers' perceptions of the CSA technology specific attributes. The Kaizer criterion (1960) was used for selecting the number of essential factors or principal components explaining the data. All components with Eigen values of less than one were left out, following the rule of thumb when conducting Principal Component Analysis (PCA) using correlation matrix [see (Mugi-Ngenga *et al.*, 2016)]. Subsequently, the factor loadings for the reduced components as suggested by the criterion of Eigen values were retained for further analysis. The 5 factors extracted explained 63% of the variance in the 19 CSA technology specific characteristic components. These factors are:

Factor 1: Training and demonstration related to DTSVs, accounts for 23.7% of the variance. Adequate opportunities for training, training, access to agricultural advisory services and well demonstration related to DTSVs, loaded heavily in this factor. The loadings for all the items had positive signs, implying that these four CSA technology specific characteristics are positively correlated. That is, they are likely to influence adoption of CSA technologies. The result implies that farmers with adequate opportunities for training and demonstration are also likely to be trained often and have regular access to agricultural services.

Factor 2: Knowledge possession and benefits related DTSVs, explained 14.8% of the total variance in the 19 CSA technology specific characteristic variables. Farmers' knowledge about DTSVs and its better planting dates as well as its ability to enhance yield, safeguard households' food security and to offers immediate benefits loaded heavily in this factor. The loading for all the variables had positive signs, suggesting that they are positively correlated, likewise, likely to influence CSA technology adoption. Farmers who have knowledge about the DTSVs and their better planting, also attested that the DTSVs is likely to offer them immediate benefits while enabling them to enhance their yield as well as safeguarding their household food security. These corroborated the findings of Senyolo *et al.*, 2018.

Factor 3: Knowledge and experience on non-agricultural activities, accounts for 12.2% of the variance. Knowledge of non-agricultural activities, relevant experience to get employment outside agriculture, consideration of knowledge about other activities other than agriculture and signal to consider non-agricultural opportunities loaded heavily in this factor and with positive signs, reflecting positive correlation. These variables give an indication of farmers' decisions when faced with alternative opportunities outside agriculture. Farmers' with knowledge of better non-agricultural activities and relevant experience to get employment elsewhere may not adopt CSA technology and instead focus on alternatives. However, Langat *et al.* (2013) indicate that off-farm income often complements, rather than replaces farm income, potentially increasing the affordability of new (CSA) technologies.

Factor 4: Necessary requirements, explained 7.2% of the total variance in the CSA technology specific characteristics variables. The importance of receiving tractor services on time, knowledge on better planting dates of DTSVs and whether information loaded heavily with positive signs in this factor, also implying positive correlation. Based on farmers' opinions, it is important for them to receive tractor services on time, to be informed about better planting dates and to receive weather forecasts. During FGDs farmers indicated their frustration of receiving tractor services and other inputs late in the season which in turn impacts planting dates recommended for DTSVs. Thus, timing in the delivery of inputs and services is important in agriculture.

Factor 5: Enabling factors to adopt DTSVs and other CSA technologies, explained 5.15 of the total variance in the CSA technology specific characteristics variables. Variables additional training on DTSVs and information as well as knowledge about other CSA technologies would increase the ability to adopt DTSVs and other CSA technologies, respectively loaded heavily in this factor. The loadings for all the variables had positive signs, implying positive correlation. We concur with the interviewed farmers that despite the preference and reasons of those promoting a particular technology at a point in time, it is necessary and relevant to still be informed about alternatives as well as this will enhance their chances to adopt CSA technologies and practices that suit them best.

In the following subsection, the explained factors together with other socio-economic variables are used in the MNLR model as variables.

1.4. Multinomial Logistic Regression

Multinomial Logistic Regression (MNLR) model was used to analyse the factors influencing smallholder farmers' choice of seed varieties. This was done to understand the drivers and barriers to adoption of CSA technologies such as DTSVs. MNLR model for the choice of seed varieties specifies the relationship between the probability of choosing a particular seed variety and the set of explanatory variables. MNLR can use standard regression techniques to select variables [see (Mugi-Ngenga *et al.*, 2016; Petrucci, 2009; Ubisi *et al.*, 2017)]. The dependent variables in the final model for this paper is the type of seed varieties that respondents in this study were using (see table 4). It was established that the sampled smallholder farmers were using three seed varieties namely: CSA technologies (Hybrids and OPVs) and traditional seeds. Therefore, the dependent variable was specified as the seed variety that farmers adopted/used, as follows: 1= "Hybrids and Hybrids with OPVs or traditional seeds"; 2= "OPVs and OPVs with traditional seeds"; and 3= "traditional seeds". The independent variables were derived from the 5 factors produced by the factor analysis, together with other socio-economic variables based on the literature (Ikheloa *et al.*, 2013; Mugi-Ngenga *et al.*, 2016; Mulaudzi & Oyekale, 2015; Senyolo *et al.*, 2018; Ubisi *et al.*, 2017).

There are numerous ways to assess the model fit in MNLR. According to Petrucci (2009), the most commonly used is the likelihood ratio test. The presence of a relationship between the dependent variable and combination of independent variables is based on the statistical significance of the final model chi-square. According to our results (not shown here), the probability of the model chi-square was .000, less than the level of significance of 0.01. These indicate that the independent variables as a group contribute significantly to the prediction of the outcome. Furthermore, SPSS generates three different pseudo R^2 summary statistics, used by some to assess model fit by determining the effect size of the model (Petrucci, 2009). For our analysis, pseudo R^2 statistics were as follows: Cox and Snell, .411; Nagelkerke, .510 and McFadden, .322. The McFadden's is a transformation of the likelihood ratio statistic, and values from .2 to .4 for McFadden are considered highly satisfactory (Petrucci, 2009).

Table 6 shows that variables "Training and demonstration related to DTSVs", "Knowledge possession and benefits related to DTSVs" and "Enabling factors" were significant in distinguishing both categories ("Hybrids seeds and Hybrids with OPVs or traditional seeds" and "OPVs seeds and OPVs with traditional seeds" of the dependent at ($p<0.005$) 5% ($p<0.001$) 1% and ($p<0.001$) 1% and ($p<0.1$) 10%, ($p<0.005$) 5% and ($p<0.005$) 5%, respectively, when compared with "traditional seeds" category. Farmers who had adequate opportunities for training, training and access to agricultural advisory services and those whom DTSVs were demonstrated in their areas were more likely to use the DTSVs. Thus, if farmers had adequate training and adequate opportunities for training, access to agricultural advisory services, weather forecasts and demonstrations related to DTSVs, they are 2.2 and 2.1 times likely to use "Hybrids and Hybrids with OPVs or traditional seeds" and "OPVs seeds and OPVs with traditional seeds" relative to "traditional seeds", respectively. These results corroborate with previous research suggesting that receiving information on improved farming and contact with extension significantly explained the adoption of improved fallows among smallholder farmers (Matata *et al.*, 2010). Farmers who have information about whether forecasts, are likely to adjust their planting decisions. Furthermore, these results agree with similar results by Kielbasa (2016), who indicated that although education is important, it must be supported by experience, and verified in practical situations.

Similarly, farmers who acquired knowledge about DTSVs and their better planting dates as well as familiarity with the perceived benefits of DTSVs were also likely to use the technology. Thus, the adoption of Hybrids and OPVs relative to traditional seeds was associated with farmers' knowledge and awareness of the benefits of those technologies. Thus, farmers' knowledge of DTSVs, recommended planting dates, and related benefits (i.e. enhanced yields and food security, and offering of immediate benefits) were significant ($p<0.000$) and ($p<0.027$)

predictors in distinguishing farmers who were using “Hybrids and Hybrids with OPVs or traditional seeds” and “OPVs and OPVs with traditional seeds” from those that were using “traditional seeds”, respectively (table 6). Accordingly, farmers who were aware of Hybrids and OPVs and thought they gave benefits such as immediate benefits, increased yield and improving households’ food security, were 3.0 and 2.1 times more likely to use “Hybrids and Hybrids with OPVs or traditional seeds” and “OPVs and OPVs with traditional seeds” relative to “traditional seeds”, respectively. These results concur with research that found that if farmers believe that DTSVs were responsible for high yield and enhanced food security, they are most likely to adopt them to improve their livelihood (Diale, 2011; Ikheloa *et al.*, 2013; Senyolo *et al.*, 2018).

Moreover, farmers’ in the study area believed that additional training as well as knowledge and information would increase their ability to use Hybrids and/or OPVs seeds and other CSA technologies, respectively. Thus, our results indicated that farmers who are further trained, informed about DTSVs and other CSA technologies were 2.6 and 2.2 times more likely to use Hybrids and OPVs respectively, as compared to traditional seeds. Furthermore, the results also revealed that though farmers appreciated the DTSVs, they deemed it was also necessary to be trained and be informed of other CSA technologies. These results are in line with Katengeza *et al.* (2012) and Mulaudzi and Oyekale (2015) who note that trait preferences of farmers form the basis of their selection of varieties.

The following variables: “necessary requirements”, gender, marital status and credit access were significant in distinguishing category 1 and category 2 of the dependent variable. Also, the interpretation of an independent variable’s role in differentiating the dependent variable groups is the same as used in binary logistic regression. However, the difference in MNLR is that we can have multiple interpretations of an independent variable in relation to different pairs of groups. Thus, one of the strengths of MNLR is that different estimates are computed for all paired groupings of the dependent variables. Because of this, different effects of variables within each group can be identified. In this paper, we computed estimates for the different types of seeds that our sampled farmers used. From the analysis, it can be established that the statistically significant variables influence farmers’ likelihood to choose certain varieties of seeds in response to climate change related impacts.

For instance, the coefficient (.803) and odds (.448) ($p<0.1$) in table 6 for necessary requirements suggest that if the respondents are informed about weather information (i.e. temperatures and rainfall) in their area, they know about better planting dates for DTSVs and receive tractor services on time to plant DTSVs, they are 0.4 times as likely to use Hybrids than traditional seeds. Therefore, in the following subsection, we discussed variables that distinguished the likelihood of using “Hybrids and Hybrids with OPVs or traditional seeds” when contrasted with “traditional seeds”.

The MNLR model revealed that variable “necessary requirements” has been found to be significant on one occasion in distinguishing between pairs of groups. Necessary requirements related to DTSVs were only significant when the outcome variable “Hybrids and Hybrids with OPVs or traditional seeds” was being compared to outcome variable “traditional seeds” (table 6). This implies that the more farmers are informed about weather information (i.e. temperatures and rainfall) in their area, know about better planting dates for DTSVs and receive tractor services on time to plant DTSVs, the higher the odds of the farmers using “Hybrids and Hybrids with OPVs or traditional seeds” relative to “traditional seeds”. Thus, if farmers are informed about weather information (i.e. temperatures and rainfall) in their area, know about better planting dates for DTSVs and receive tractor services on time to plant DTSVs, they are 0.4 times likely to use “Hybrids and Hybrids with OPVs or traditional seeds” relative to “traditional seeds”. During FGDs farmers indicated their frustration of receiving tractor services and other inputs late in the season which in turn impacts planting dates recommended for DTSVs. However, timing in the delivery of inputs and services is important in agriculture, particularly within smallholder agriculture where several barriers are farmers’ reality.

The results show that female farmers in the study area were 0.4 times less likely to adopt the Hybrids seeds relative to using traditional seeds. Gender of the respondents was a significant ($p<0.1$) negative predictor of whether the farmers were using “Hybrids and Hybrids with OPVs or traditional seeds” relative to those that were using “traditional seeds” only. These could be because our sampled population comprised more female farmers (Oluwatayo & Ojo, 2016), who tend to prefer and managed to save seeds for the next farming season as compared to their male counter parts. These results concur with Ikheloa *et al.* (2013) who noted that male-headed households have the tendency to adopt climate adaptation strategies much more than female-headed households. However, Bayard *et al.* (2007) and Mugi-Ngenga *et al.* (2016) found that female farmers are more likely to adopt strategies to adapt to climate variability. Nevertheless, gender has a negative relationship to both the use of hybrids seeds and OPVS.

Marital status of the respondents was only significant ($p<0.1$) in distinguishing the farmers who were using “Hybrids and Hybrids with OPVs or traditional seeds” relative to those that were using “traditional seeds” (table 6). The results indicate that farmers who were never married were 0.2 times less likely to use “Hybrids and Hybrids with OPVs or traditional seeds” relative to “traditional seeds”. Marital status has previously been found to be insignificant in influencing the choice of adaptation strategies and technology adoption (Matata *et al.*, 2010; Mugi-Ngenga *et al.*, 2016; Ubisi *et al.*, 2017). Our results relate with Mulaudzi and Oyekale (2015) who found a positive statistically significant relationship between marital status and adoption of improved varieties of seeds. Oluwatayo and Ojo (2016) also found a positive relationship between marital status and the likelihood of choosing diversification as an adaptation strategy. Furthermore, the highest percentages of married farmers observed in the study suggest that adoption of DTSVs in the study depends on the perception of the technology by males, as it may be common that women do not own land and/or other resources to take autonomous adoption decision.

Moreover, it was found that access to credit positively increased the use of “Hybrids and Hybrids with OPVs or traditional seeds” relative to “traditional seeds” (table 6), corroborating research that found that access to credit facilities positively increased the use of different adaptation strategies (Ikheloa *et al.*, 2013; Oluwatayo & Ojo, 2016). Thus, farmers who have access to credit are 4.6 times more likely to use “Hybrids and Hybrids with OPVs or traditional seeds” relative to traditional seeds. However, there is a negative relationship between access to credit and use of “OPVs and OPVs with traditional seeds” This implies that as a farmer gains more access to credit, the likelihood of adopting “OPVs and OPVs with traditional seeds” decreases.

It should be noted that the discussion was limited to independent variables that were significant in distinguishing the 2 categories of the dependent variable related to the “traditional seeds” category (i.e. base category). The reason for this was that looking at the characteristics of DTSVs as perceived by the farmers and other socio-economic factors; knowledge and experience on non-agricultural activities, age, household size, farming experience, education, income reason for farming, land size, government support and cooperative membership; were found not to be significant in distinguishing both categories “Hybrids and Hybrids with OPVs or traditional seeds” (1 and 2) related to “traditional seeds” within their crop farming. Therefore, these variables were not included in the interpretation.

Table 7: Classification table from the multinomial logit model

Observed	**Predicted**			
	Hybrids and hybrids with OPVs or traditional seeds	OPVs and OPVs with traditional seeds	Traditional seeds	Percent Correct
Hybrids and hybrids with OPVs or traditional seeds	**125**	3	8	91.9%
OPVs and OPVs with traditional seeds	16	**7**	1	29.2%
Traditional seeds	13	0	**23**	63.9%
Overall percentage	**78.6%**	**5.1%**	**16.3%**	**79.1%**

While, MNLR computes correlation measures to estimate the strength of the relationship (Pseudo R^2 measures, such as Nagelkerke and Cox and Snell's R^2), these correlation measures do not actually tell us much about the accuracy or errors associated with the model. Thus, a classification table is considered another indicator of the usefulness of the final model (Petrucci, 2009) and is presented in table 7. In order to assess the utility of the MNLR model, classification accuracy is more useful and compares predicted group membership based on the logistic model to the actual, known group membership, which was the value for the dependent variable. Even, if the predictor variables had no relationship to the groups defined by the dependent variable, the predictions would still be expected to be correct for group membership some percentage of the time. This is referred to as by chance accuracy (Petrucci, 2009). Correctly classified cases are on the diagonal in table 7 (i.e. "Hybrids and Hybrids with OPVs or traditional seeds" category, "OPVs and OPVs with traditional seeds" category, and "traditional seeds" category). Overall, the final model accurately predicted 79.1% of the cases. However, we see that the "Hybrids and hybrids with OPVs or traditional seeds" category had a much higher prediction at 91.9% compared to other 2 categories.

The estimate of by chance accuracy is computed by summing the squared percentage of cases in each group. The difference between by chance accuracy for binary logistic models and by chance accuracy for multinomial logistic models is the number of groups defined by the dependent variable. The proportional-by-chance accuracy rate was computed by calculating the proportion of cases for each group based on the number of cases in each group in the 'Case Processing Summary' (see table 4), and then squaring and summing the proportion of cases in each group ($0.694^2+0.122^2+0.184^2=0.531$). The proportion by chance accuracy criteria is 66.4% (1.25 x 53.1% = 66.4%). Since the classification accuracy rate of 79.1% (see table 7) was greater than the proportional-by-chance accuracy criteria of 66.4%, the model improves on chance 25% or more and is considered adequate.

4. Conclusions, implications for policy and further research

DTSVs is a CSA technology for addressing moisture stress and water scarcity related to climate change and variability. Results showed smallholder farmers in the study area were using three seed varieties namely: CSA technologies (Hybrids and OPVs) and traditional seeds. We find that despite the acknowledged potential of such technologies, drivers and barriers exist, which impact the adoption and use of such technologies. For instance, variables "Training and demonstration related to DTSVs", "Knowledge possession and benefits related to DTSVs" and "Enabling factors" were significant in distinguishing both categories ("Hybrids seeds and Hybrids with OPVs or traditional seeds" and "OPVs seeds and OPVs with traditional seeds" of the dependent at 5%, 1% as well as 1% and 10%, 5% as well as 5% significant levels respectively, when compared with "traditional seeds". Furthermore, the following variables: "necessary requirements", gender, marital status and credit access were significant in distinguishing category 1 of the dependent variable. These results are valuable to policymakers and technology developers as they highlight the key factors that impact farmers' adoption decisions.

Farmers in the study area report that enabling factors such as additional training and information would increase their ability to adopt DTSVs. Our results highlight that training and demonstration related to DTSVs, knowledge possession and awareness of benefits related DTSVs and enabling factors were important for all the categories of the dependent variable. It can be recommended that Department of Agriculture, Forestry and Fisheries (DAFF), Provincial Departments of Agriculture and Agricultural Council as well as private companies work together to improve adoption of DTSVs to establish functional regulatory board in order to work closely with the farmers and to educate them about the seeds and their benefits so as to safeguard food security as well as improve farm incomes. Working closely with farmers will enable them to assess the most suitable seed varieties for a given area and farm system, together with farmers' ability to adequately adopt seeds in question.

The results also indicate that training and demonstration were significant in impacting farmers' adoption of DTSVs relative to traditional seeds. In this instance, policymakers and other stakeholders can mobilize their resources and coordinate their efforts to provide training and demonstration to farmers regarding the DTSVs to enhance adoption of these technologies. The results also highlight that farmers in rural areas are heterogeneous, with some having better capabilities to adopt different CSA technologies; therefore, how other stakeholders engage farmers through education, training and any form of assistance related to CSA technologies should be tailored to suit farmers' different needs and capabilities. Furthermore, the results highlight that access to effective training, agricultural advisory service and weather forecasting impacted adoption. The strengthening of existing extension services as well as engagement with the private sector (e.g. technology providers), could help overcome the barriers of lack of knowledge and finances, thereby safeguarding adequate adoption by farmers.

Results indicated that variable necessary requirements related to DTSVs was significant when the outcome variable "Hybrids and Hybrids with OPVs or traditional seeds" was being compared to outcome variable "traditional seeds". Thus, farmers highlighted that it is important that they are informed about weather information (i.e. temperatures and rainfall) in their area, know about better planting dates for DTSVs and receive tractor services on time to plant DTSVs. However, during FGDs farmers indicated their frustration of receiving tractor services and other inputs late in the season which in turn impacts planting dates recommended for DTSVs. Yet, timing in the delivery of inputs and services is important in agriculture. Therefore, Provincial Departments of Agriculture in South Africa need to relook into their planning and supply chain processes in order to improve the effectiveness of their input delivery system to smallholder farmers.

Our results indicated that female farmers were less likely to adopt the Hybrids seeds relative to using traditional seeds. Gender issues within climate change related studies are not new and continue to yield mixed results. In Ikheloa *et al.* (2013) male-headed households showed a tendency to adopt climate adaptation strategies, while in Bayard *et al.* (2007) and Mugi-Ngenga *et al.* (2016) female famers were more likely to adopt strategies for climate variability adaptation. Perhaps potential issues arise during survey processes. It can be recommended that a specific study be conducted in South Africa and pay attention to potential gender issues during survey process to ascertain the conditions which hinder or enable women to adopt CSA technologies such as DTSVs.

Credit access was also a significant factor, again illustrating the difficulty of farmers' access to agricultural production credit. It can therefore be recommended that farmers' access to credit be enhanced so as to beef-up their capacity to adopt CSA technologies such as DTSVS. Ikheloa *et al.* (2013) alluded that improving farmers' access to credit and extension will boost farmers capability to use various adaptation strategies to respond to climate variability. This is also important given that affordability of DTSVs remains a challenge. Department of Land Reform and Rural Development in partnership with DAFF could work to together to fast-track the pillar of land reform responsible for provision of title deeds and adequate post-settlement support that farmers will need to ensure transferred farms remain viable. Ownership of land accompanied by adequate sufficient support will empower the farmers in several ways that include ability to produce food as well as to use the land as a collateral to obtain production credit which is a necessity for commercial production. Policymakers could help farmers obtain title deeds of the land they use for agriculture, so this land can be used as collateral to obtain production credit in formal institutions. Some farmers in the study area sourced their credit from informal institutions, often even considered ‘illegal’; as they see these as alternative options in the absence of support from formal institutions such as commercial banks, government, and the private companies. Further research could unpack other sources of production credit and how they function, to complement the provision by formal institutions.

Although it is undeniable that local provision of seeds has the potential to reduce the higher transaction costs of procuring DTSVs, the concern raised by some farmers over issues of trust regarding production and marketing of quality seeds at local level demand further attention. Therefore, government, private sector and universities should join forces and mobilize resources to invest in organizing and empowering more farmers to engage in community-based seed production that farmers can all trust. Furthermore, knowledge of these enabling and hindering factors to adopting CSA technologies such as DTSVs will also contribute to the emerging literature as well as the global research and policy debate regarding CSA.

4

Climate-smart agriculture diffusion in bottom-of-the-pyramid contexts: the role of business models of Agri-technology providers

This chapter is based on: Mmapatla Precious Senyolo, Thomas B. Long, Vincent Blok, and Onno Omta. "Climate-smart agriculture diffusion in bottom-of-the-pyramid contexts: the role of business models of Agri-technology providers ". Under-review with the *International Food and Agribusiness Management Review Journal*.

CHAPTER 4

1. Introduction

Agriculture faces serious threats due to climate change, calling for increases in resilience to climate impacts and potential greenhouse gas (GHG) emission reductions (Arslan *et al.*, 2015). Agriculture must also feed a growing population. These grand challenges are exacerbated in developing regions, such as Africa, where smallholder farmers are often marginalized and highly vulnerable due to resource and knowledge constraints (Chandra *et al.*, 2018; Grainger-Jones, 2011). Smallholder farmers are an important group: they provide up to 80% of food for developing countries, manage sizeable areas of land (especially in sub-Saharan Africa and Asia) and constitute the largest share of the developing world's undernourished (Grainger-Jones, 2011; IFAD, 2013). These challenges require a transition to a more sustainable agricultural system, in order to provide livelihood to smallholder farmers.

Climate Smart Agriculture (CSA) represents one solution and aims to improve agricultural productivity while reducing GHG emissions and adapting to climate impacts (Chandra *et al.*, 2018; FAO, 2010; McCarthy *et al.*, 2011; Senyolo *et al.*, 2018). CSA involves both new and established technological, policy and institutional interventions (Kaczan *et al.*, 2013). CSA technological innovations (CSATIs) include technologies that increase productivity while reducing greenhouse gas (GHG) emissions and climate change impacts (FAO, 2010; Scherr *et al.*, 2012; Taneja *et al.*, 2014). A wide range of these technologies and practises such as water management (harvesting and saving), crop management, agroforestry, and conservation agriculture, exist.

Adoption of CSATIS by smallholder farmers is slow regardless of their benefits (Braimoh, 2015; Kaczan *et al.*, 2013; Kuppanan Palanisami *et al.*, 2015; Van Eck *et al.*, 2017). The adoption and diffusion of CSATIs is impacted by both supply and demand factors. Previous research highlights key factors such as lack of finance to invest, high costs and poor understanding of farmers' needs (Below *et al.*, 2012; Deressa *et al.*, 2011; Khatri-Chhetri *et al.*, 2017; Murray *et al.*, 2016; Senyolo *et al.*, 2018). Several demand-side barriers can be traced back to a limited understanding of user needs by those who design and provide innovations (Long *et al.*, 2016). Supply-side barriers include lack of supporting partnerships, difficulty in reaching and convincing customers, leading to difficulty in providing impact (Long *et al.*, 2017). Supply and demand side barriers are likely to interact, and so overcoming barriers to adoption of CSATIs must involve tackling both supply and demand sides (Long *et al.*, 2017; Montalvo, 2008).

Few studies explicitly explore the interrelations between both supply and demand side barriers (Blok *et al.*, 2015; Long *et al.*, 2016; Long *et al.*, 2017). A business model approach could facilitate such an exploration. The business model construct connects supply and demand sides, as it explores and explains the core logic of a business and allows a reflection on how to capture value from providing new products and services that add value for the customer (Bocken *et al.*, 2014; Teece, 2010). Business model innovation can improve technology diffusion by "re-conceptualising the purpose of the firm and the value creating logic, and rethinking the perceptions of value" (Bocken *et al.*, 2014).

The aim of this paper is to explore the factors that affect the ability of CSA technology providers to diffuse CSATIs to smallholder farmers at the base-of-the-pyramid (BoP), by examining their business models. Using the business model as an analytical lens, this article explores the interaction between demand and supply by reflecting on the value propositions of technology providers for their customers (e.g. farmers), and the value captured by their products and services (i.e. CSATIs). Low adoption rates among the BoP have been tackled through government and NGO initiatives, but with limited success. Kubzansky (2012) note that "the single biggest factor that enables private sector-led approaches to reach a meaningful scale in dealing with BoP markets is getting the business model right". A technology will not succeed without an appropriate business model (Boons & Ludeke-Freund, 2013; Chesbrough, 2010; Long *et al.*, 2017). Thus, the research question of this study is: *What factors enable and hinder the ability of business models used by agri-technology providers in South Africa to diffuse CSATIs?*

By exploring agri-technology provider's business models within the smallholder farming context in South Africa, this article contributes to our understanding of the barriers to CSATI's adoption, and the opportunities to enhance CSATIs adoption and diffusion. Moreover, recent research has highlighted the specificities of BoP contexts (Yessoufou *et al.*, 2018) and a key a role for the private sector in developing and delivering innovative technologies for BoP communities. Business models must be adjusted to these contexts to be successful (Blok *et al.*, 2013; Chesbrough, 2010; Linna, 2012; Long *et al.*, 2017; Teece, 2010). For instance, Gray *et al.* (2014) argue that for business model to be financially worthwhile, it is necessary that they develop overtime in order to manage the changing market opportunities and environmental threats. Appropriate business model should assist smallholder farmers at the BoP to adopt CSATIs, helping these users to overcome adoption barriers. However, business model meant for the BoP in general, and smallholder farmers and CSA contexts in particular has received inadequate attention in the literature (Foster & Heeks, 2013; King & Lynghjem, 2016).

2. Literature Review

2.1 Business models and technological innovations

A business model explains how an organisation functions to deliver value to its target market whilst generating profit (Osterwalder & Pigneur, 2004; Ver Loren van Themaat *et al.*, 2013). All companies employ a particular business model, either explicitly or implicitly. A business model comprises four pillars, namely; product (value proposition), customer interface (target customer, distribution channel, and relationship), infrastructure management (value configuration, core competency, partner network) and financial aspects (cost structure, revenue model). These components together comprise the "business model canvas", a popular business modelling tool, and provide companies with the opportunity to think and conceptualise how they add and capture value, and to explore alternative options (Osterwalder *et al.*, 2005; Ver Loren van Themaat *et al.*, 2013). While the business model concept is useful to understand how firms do business (Bocken *et al.*, 2014; Osterwalder *et al.*, 2005), literature highlights that the business model has the potential to provide a broader perspective on the core activities of the company (e.g. organizational design, resource-based view, transactive structure, etc.) (Spieth *et al.*, 2014).

There is growing recognition in the literature that conventional business could integrate sustainability into their business through cautious redesigning of their business model, whilst new business could pursue sustainable businesses from the onset (Bocken *et al.*, 2014). Sustainable business models deal with creation and capturing value as well, and show, for instance, how technological innovations create economic, social and environmental value for customers and society at large (Abdelkafi & Täuscher, 2016; Bocken *et al.*, 2014; Stubbs & Cocklin, 2008). Literature indicate that entrepreneurs have through their support services and/or innovative business models addressed economic, social and/or ecological challenges in poor countries; in response market and aid program failures (Gray *et al.*, 2014; Xiao & North, 2018).

A business model is also critical to technology adoption. Teece (2010) argued, "technological innovation often needs to be matched with business model innovation if the innovator is to capture value". Indeed, a good technology will fail without an appropriate business model (Chesbrough, 2010). The reason is that business models enable technology providers to focus on providing customer solutions to their perceived needs (Teece, 2010). In the context of this research, this means that CSA technology providers develop technologies that are the 'best' from an engineering perspective, but provide a solution for the economic and environmental needs experienced by the farmers.

2.2 Business models at the base-of-the-pyramid

The potential of agribusinesses to support the adoption of CSA has received relatively little attention because business is often seen as part of the problem. This is because commercially orientated actors often pursue short-term gains at the expense of human development and the environment, and because of their tendency to focus on easier-to-reach segments and markets, requiring less business model adjustment and cost (Connolly & Phillips-Connolly, 2012; Kubzansky, 2012). Many development actors and agribusiness leaders now increasingly believe that one of the key ways to attain large-scale social-impact is through commercially sustainable solutions (Connolly & Phillips-Connolly, 2012; Kubzansky, 2012). These means agri-technology providers will increasingly be expected to deliver agricultural technologies to enhance productivity, whilst addressing sustainability aims, such as climate mitigation and adaptation. The business models of agri-technology providers may have to be adjusted to fulfil these aims and provide new added value to farmers in BoP contexts (Blok *et al.*, 2013; Chesbrough, 2010; Linna, 2012; Long *et al.*, 2017; Teece, 2010).

Adjustments to the business models of agri-technology providers could benefit smallholder farmers in a number of ways (Agnihotri, 2013; Teece, 2010). Business models will have to take into account the limited access to extension, financing, and other supporting services by smallholder farmers (Murray *et al.*, 2016), as well as low productivity, high transaction costs, poor access to inputs and markets. Despite the difficulties faced by smallholder farmers, some case studies show the potential for business model innovation to provide a solution. However, these studies are conducted almost exclusively in Asia and Latin America, leaving an African context knowledge gap (King & Lynghjem, 2016).

Our framework for answering our research question focuses on the business models of agri-technology providers. This will allow an exploration of how business models and the key factors around them influence technology adoption for CSA. To do this we adopt the abridged version of four interrelated components of the business model noted by Magretta (2002) to highlight key factors for business model for CSATIs (BM*f*CSATIs). Analysing the agri-technology companies' business models will allow identification of specific key issues and understanding of the business logic of the agri-technology providers. In the following subsection, we highlight how each aspect of the business model influences technology adoption and how this relates to enhances the use of CSATIs among smallholder farmers in BoP settings.

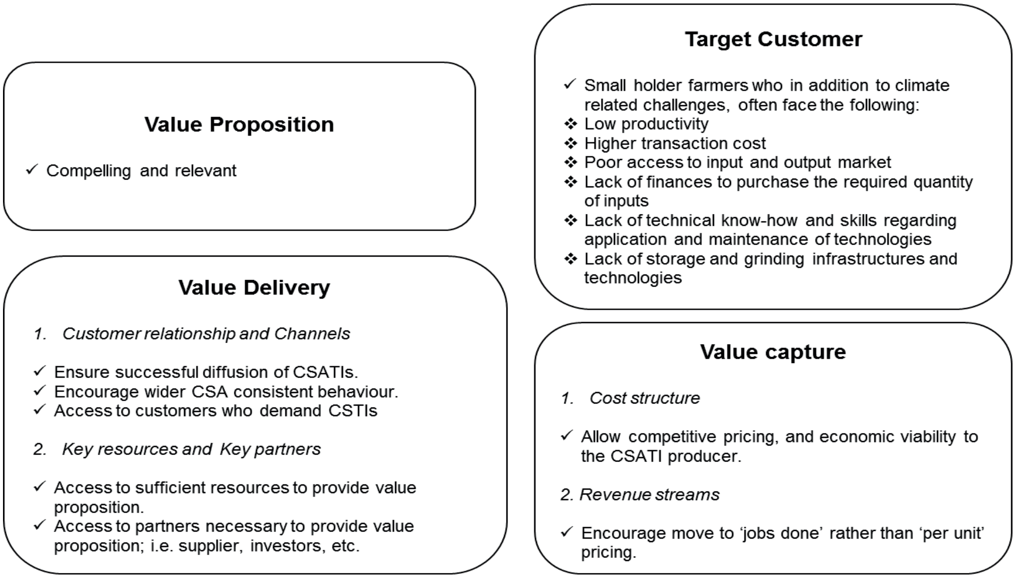

Figure 1: Critical issues for the BM*f*CSATIs, based on the literature (Gabriel & Kirkwood, 2016; Long *et al.*, 2017; Magretta, 2002; Osterwalder & Pigneur, 2010).

The value proposition describes how a firm caters to their target customers' needs. This component articulates how the companies offer value to their customers, commonly through products and services (Gabriel & Kirkwood, 2016; Osterwalder & Pigneur, 2010). A good value proposition has to tackle the challenges that end-users face (Long *et al.*, 2017), as customers do not solely desire products, but want solutions to their perceived needs (Teece, 2010).

The target customer defines the specific segment targeted by the companies. Our context focuses on the smallholder farmers within BoP settings. Smallholder farmers face major disadvantages which include: low productivity, higher transaction costs, poor access to input and output market, lack of adequate finances to purchase the required quantity of inputs, lack of technical know-how and skills regarding application and maintenance of technologies, lack of storage and grinding infrastructures and technologies (Blok *et al.*, 2013; Ricker-Gilbert & Jones, 2015). These challenges imply a high cost for servicing the smallholder farmers segment, with narrow profit margins (Karnani, 2007), with potential profits in the far future (King & Lynghjem, 2016).

Value delivery focuses on how a business delivers the value they create and the resources and activities involved in delivering the value. It is within this element that we understand whether companies are engaged in a 'once-off' sales, or whether they offer additional 'after-sale' services (Long *et al.*, 2017). The relationship between customers and the companies is especially important for business model for sustainable innovations (BM*f*SI), considering that it is during this and within these forged relationships that user-behaviour can be influenced (Boons & Ludeke-Freund, 2013; Long *et al.*, 2017). Successful diffusion of sustainable innovations such as CSATIs would benefit from broader sustainability actions, market acceptance and limited rebound effects which can be influenced through customer relationships (Byrne & Polonsky, 2001; Long *et al.*, 2017).

For companies to deliver the value they create, reach their targeted customers and maintain relationships, while earning the profits, they need resources and partners. For instance, firms form partnerships to reduce risk, acquire resources, as well as to optimize their business models (Osterwalder & Pigneur, 2010). Access to a broader and heterogeneous network which comprise scientific, social, economic, political and cultural linkages is necessary for backing and encouraging sustainable innovations, particularly when they are radical (Ceschin, 2013).

Value capture is concerned with how companies capture some of the value they create in the form of profit. This component corresponds with all the components (i.e. value proposition, value delivery, and target customer) of the business model (Gabriel & Kirkwood, 2016); because to create the company's earnings, all costs incurred while creating and delivering value and maintaining customer relationships will be subtracted from the generated revenues (Osterwalder & Pigneur, 2010). The rationale behind value capture is to maximize earnings through costs minimization and attainment of competitive price as far as possible. Previous research notes that the end users' price consideration remains a relevant factor when it comes to demand of both sustainable and conventional innovations (Long *et al.*, 2017).

3. Methods: data collection and data analysis

The paper seeks to answer the question: *What factors enable and hinder the ability of business models used by agri-technology providers in South Africa to diffuse CSATIs?* The research took an in-depth qualitative approach. This was felt to be an appropriate research design as (1) little is known of CSA technology providers in the developing countries context, while (2) our research questions were of a 'why' and 'how' nature. The study relied on data from in-depth interviews with agri-technology providers, which where triangulated with the aforementioned literature in the fields of CSA, technological innovations and business models.

3.1 Data collection

A non-probabilistic purposive sampling strategy (Arinloye *et al.*, 2015; Palinkas *et al.*, 2015) is used, together with using referrals from existing contacts and internet searches to identify respondents for this study (see table 1 for list of respondents). Ten face-to-face, semi-structured interviews were conducted, ranging from 45 minutes to 90 minutes. The lead author conducted the interviews between July and August 2017 at the respondents' work places. Informed consent was obtained prior to each interview. Most of the interviews were audio taped and transcribed by the interviewer, and where this was not the case, comprehensive notes were taken during the interview. The specific personal identifying information was removed during transcription to provide anonymity to the respondents.

The interviews were carried out using a flexible interview protocol (see the appendix). The interview protocol covered seven areas of questions that explored:

I. Interviewee background (e.g. respondent position and duration within the company, respondent's field of study, thoughts/views about sustainability and on the role of technological innovations to offset the climate change related impacts);
II. Company perspective (e.g. whether company have technology transfer component, established and/or required partnerships with other stakeholders and/or clients;
III. Information about the technology (e.g. what does the technology do and its value to end-users including its contribution to address climate change related challenges);
IV. Clients and adoption process (e.g. current or targeted customers, compatibility and applicability of the technology, existence of competitors);
V. Barriers to dissemination of CSA technologies (e.g. challenges related to technology dissemination, areas where support is needed, perceived enabling and limiting factors);
VI. Revenues and/or costs (e.g. costs charged for the technology and options for payment offered to farmers
VII. Policy environment (e.g. any policy or rules for the CSA technology in question and how it is thought to create opportunities or disturbances for adoption).

3.2 Data analysis

Consistent with an in-depth qualitative approach, data analysis started with the production of interview transcripts. The data, in the form of transcripts, were coded in an iterative process. This involved reading and re-reading of the transcripts throughout the analysis as new questions and connections were identified (Starks & Brown Trinidad, 2007). Statements and phrases relevant to the research questions were identified during this stage of the analysis (McIntyre *et al.*, 2011). A preliminary set of themes were developed at this stage (e.g. 'Barriers to technology dissemination'), and then refined through further iterations. Following coding of initial themes, the transcripts were re-read to identify relationships between themes identified during the preliminary stages of coding to place them into key categories. The categorisation involved several iterations to safeguard consistency within the developed categories.

Table 1: List of interview respondents, including the agri-technology type and offered products

Respondent No	Company type	Products/technology
R1	Milling Company	Provide postharvest storage and milling technologies. Also sell seeds/fertilizers/agrochemicals on behalf of other companies
R2	Agricultural Cooperative Company	Product ranges include irrigation, gardening, hardware, power tools, tractors and other farm implement spares and parts, animal feeds, seeds, fertilizers, animal health products, pet food, pet accessories, gardening chemicals, and agricultural chemicals. Also provide a storage and milling technology.
R3	Milling Company	Provide postharvest storage and milling and technologies. Also sell seeds/fertilizers/agrochemicals on behalf of other companies.
R4	Seed Company	Buy, distribute and sell both imported and local seeds.
R5	Machinery Company	Manufacture, import and sell tractors and farming implements, tractor parts and trailers.
R6	Fertilizer Company	Buy, distribute and sell fertilizers
R7	Seed Company	Produce and market seeds.
R8	Fertilizer Company	Manufacture, blender, supply and market fertilizers.
R11 (9)	Agricultural Cooperative Company	product ranges include irrigation, gardening, hardware, power tools, tractors and other farm implement spares and parts, animal feeds, seeds, fertilizers, animal health products, pet food, pet accessories, gardening chemicals , agricultural chemicals, and fuel.
R12 (10)	Seed Company	Produce, import, export and market seeds

4. Results

First, it is helpful to start with an inventory of our sample. There were five categories of agri-technology businesses in this study: Milling, Fertilizer, Seed, Machinery, and Agricultural cooperative companies. All these businesses were named after the major agri-technologies that they focused on, and those named agricultural cooperatives companies were characterised by a larger product service range which included at least four of the products offered by the other agri-technology providers. Of the ten agri-technology businesses, two were categorised under milling, two under fertilizers, one under machineries, three under seeds, and two under agricultural cooperative companies.

Having briefly indicated our sampled agri-technology providers, and established the business model framework in section 2, we now show the four types of business models used by the respondent companies for targeting smallholder farmers. The four types are ‘Engagement’, ‘Limited service’, ‘Integrated package’ and ‘Sales and procurement’; they are summarized below in table 2 and illustrated by figures 2 to 5.

We indicated in section 2 that the business model consists of four main components, namely; value proposition, value delivery, value capture and target customer. Our results highlight that factors linked to the value proposition, value capture and target customer were the most important in terms of BoP contexts. The value delivery component was not identified as a distinguishing feature between the different business models, and so we do not examine it within table 2. Instead, we commented on it briefly after the presentation of the four categories of business models identified in this study.

Table 2: Summary of business model types and number of cases that supported the models

	Engagement (2 cases)	**Limited services** (3 cases)	**Integrated package** (3 cases)	**Sales and procurement** (2 cases)
Value proposition	Handling, storage and grinding technology, Income and maize-meal for food security Bringing inputs closer Advisory services Market for output	Products Advisory services Short-term credit; Limited support and training	Products Advisory services Short to medium-term credit Integrated training and mentoring Soil analysis Precision agriculture; Maintenance Netting houses	Products Advisory services Production loans Integrated training and mentoring Market for output
Target customer	Smallholder farmers as suppliers of raw material	Smallholder farmers as end-users of products plus limited packages	Smallholder farmers as end-users of products plus integrated packages	Smallholder farmers as end-users of products plus integrated packages and as suppliers of raw material
Value delivery				
Value capture	Reduced costs for ATPs Increased volume and improved quality of grains brought by local	Reduced risks associated with credit defaults Reduced financial and time costs	Increased sales resulting from successful farmers who received support,	Increased sales resulting from successful farmers who received support, mentorship,

	smallholder farmers	associated with mentorship/training	mentorship, and production loans Increased willingness to pay	Increased volume and improved quality of seeds or grains brought by smallholder farmers

4.1‘Engagement’ business model

The main pillar of ‘Engagement’ business model is the combination of target customers and the resulting value proposition. The agri-technology providers in this category were milling companies, and responded to demands among smallholder farmers to grind their own produce, and so raising its value and reducing post-harvest losses. The milling companies provided the storage and grinding technologies. which can reduce postharvest losses. In turn, these agri-technology providers (R1 and R3) business models included buying the smallholder farmers produce. In this case, the smallholder farmers benefited through increased production and better quality maize/sorghum grains, which in turn gives them income and increased purchasing power. Moreover, in order to safeguard the volume and quality of the grains, the milling companies offered the targeted customers some advisory and logistics services. So selling and delivering the agri-technologies, such as seeds and fertilizers, is the lever that these technology providers use to facilitate their raw material gathering processes. The rationale behind this model is that if local smallholder farmers get access to timely inputs and in one place where possible, they are likely to increase their production, and the more the production from these farmers the more the raw materials available for the milling companies.

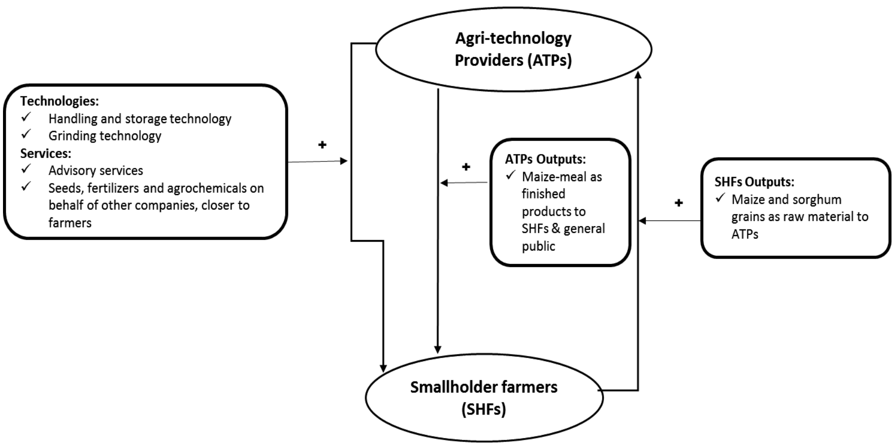

Figure 2: ‘Engagement’ business model

4.2 'Limited services' business model

The second category of business model directly sells and distributes agri-technologies to customers. In our cases, the key method is to import, distribute, and sell technologies to smallholder farmers as customers. The customer segment of the 'Limited services' business model are different types of farmers. In the case of commercial farming, the customers are large-scale commercial farmers, smallholder farmers or government contractors (i.e. tender-preneurs) on behalf of the smallholder farmers. The companies in this category had a value proposition largely focused on product sales and delivery, with limited packages of services such as advisory, training and short-term credit (see fig 3). These businesses operated their sales within commoditized and bespoke systems. They operate through either on demand supply (i.e. mail order) or via retail centres. The result is that businesses employing 'Limited services' business models became the link between the manufacturing and production companies and the farmer. Smallholder farmers are included in the formal economy by buying the agri-technologies at market price.

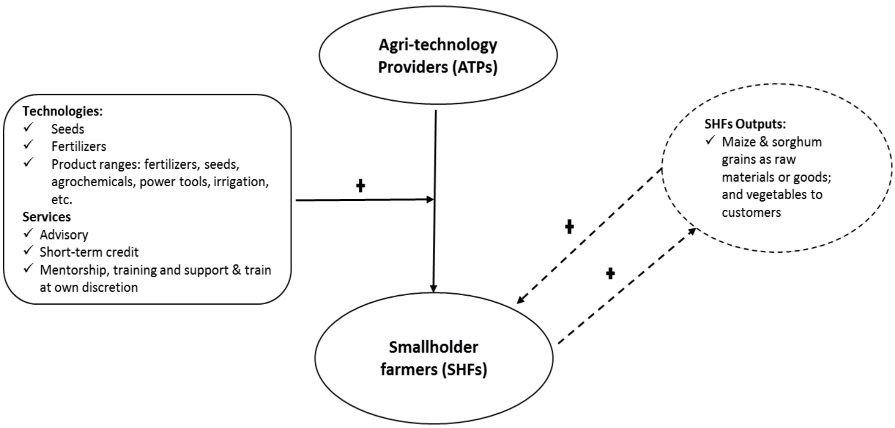

Figure 3: 'Limited services' business model

4.3 'Integrated packages' and 'Sales and procurement' business models

The third and fourth business model types both combine products with integrated services. The technology providers who employ these types of business models seem to have gained and enhanced additional strengths under market conditions, and therefore appear to have better evolved and supportive of agricultural development. As a result, they often seem to employ a larger scale form of 'Engagement' and 'Limited services' business models form. The customer segment can include both large-scale commercial farmers and the smallholder farmers or government contractors (i.e. tender-preneurs) on behalf of the smallholder farmers. The value proposition in these business models is the product-service based approach to agriculture. Notable is that whatever product-service is provided safeguards several customer needs. The agri-technology providers tend to provide the value propositions that combine the activities of the businesses that employ ‘Engagement’ and ‘Limited services’ business models (see fig 4 and 5). In the case of R2, they provide production loans together with mentorship to farmers as well as give farmers access to important production inputs and equip them with technical know-how. Another example is R5, who developed customised “developmental packages” targeted specifically at smallholder farmers, wherein their package includes a tractor, conservation agriculture implements (e.g. no till implements), maintenance plans and training. Another example is R8, who offer soil analysis together with recommendations of innovative tailor-made products in a way that protects the environment. Other examples include the provision of medium-term credit and output market for customers (e.g. smallholder farmers). While all these product-services are in essence value-creating elements, the common denominator is an increase in efficiency in everyday activities of the farmers.

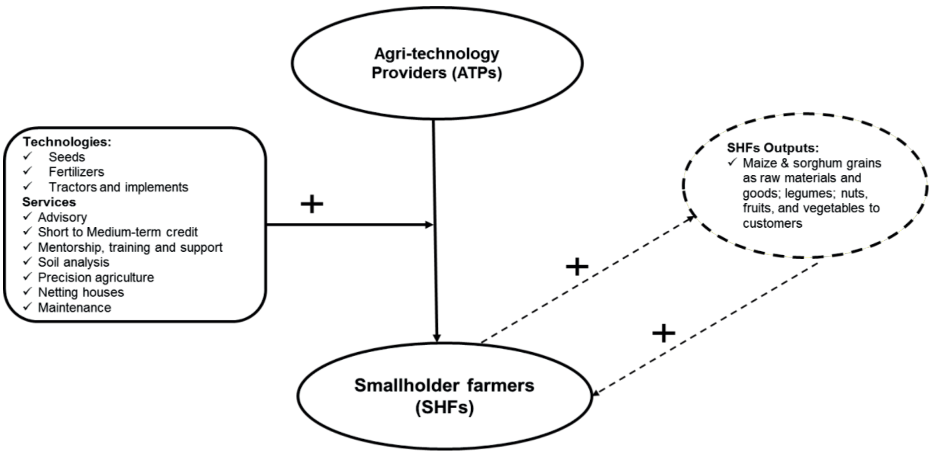

Figure 4: ‘Integrated packages’ business model

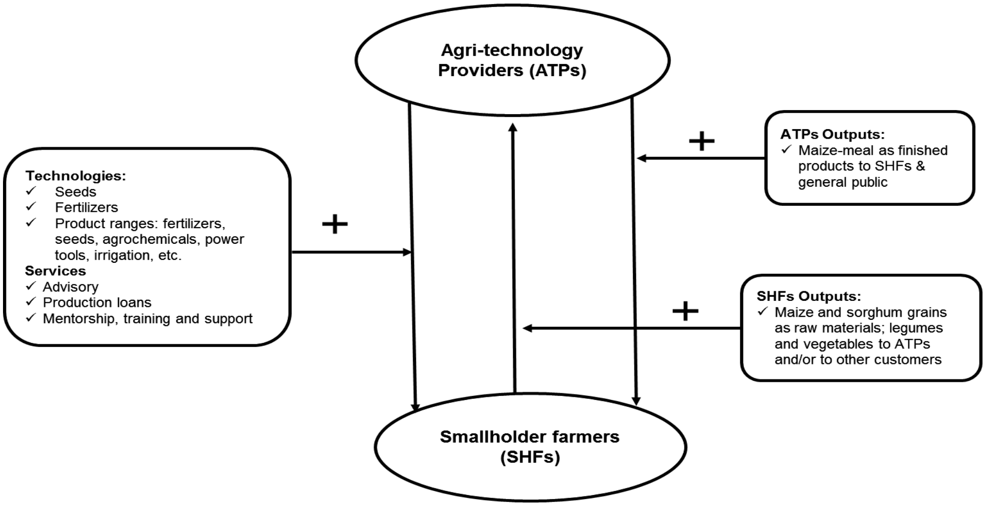

Figure 5: 'Sales and procurement' business model

4.4 Value delivery

In general, the technology providers within various business model types applied similar methods in communicating and reaching out to their customers. Due to service-based approach to agriculture that is increasingly advocated, knowledge provision and sharing is more important, meaning farmers' information field days, demos, exhibitions and internet based solutions to reach target customers are often used. For instance, almost all the business models are represented in the utilization of farmers' information field days and exhibitions to reach their customers, as R2, R10, R5, R1, R8, R7 and R9 apply these channels

4.5 Key factors of the business model from the perspectives of Agri-technology providers

The interview data collected from agri-technology providers will now be studied through the BM*f*CSATI critical issue framework, and compared to the critical issues highlighted in the literature (see figure 1). We identified the key factors of the business models of agri-technology providers and illustrated these with examples from the data. The data provides a supply perspective on the current BM*f*CSATIs, and highlights the possible shortcomings of the business model of agri-technology providers. The results show that the perceived shortcomings are for the larger part mutually identified among the different respondents. However, they differ in their strategies to address those shortcomings. Figure 6 illustrates the critical issues for BM*f*CSATs for agri-technology providers.

The first key factor related to the value proposition element noted by the respondents was that there should be a clear demand for CSATIs by farmers. According to the agri-technology providers CSATIs potentially benefit smallholder farmers considerably. Various CSATIs address critical environmental and socio-economic challenges. For instance, in relation to increased yields and soil degradation:

> *'The soil is no longer having nutrients. So it is no longer productive. So farmers need money to buy chemical fertilizers because it does not help them much if they have only seeds and they don't get fertilizers to nurture the growth of their crops.' (R8)*

> *'Most of the farmers buy hybrid seeds...they know that hybrid seeds give them the produce and profits they need.' (R1)*

> *'Smallholder farmers have challenges in terms of acquiring tractors and equipment. So what I did, I formulated a package tailored for smallholder farmers. They can get everything they require to begin farming: ripper, arrow, disc plough, trailer and tractor. All those 5 implements, and for that package of R350000, and I call it a development package.' (R5)*

Respondents noted that product-service system innovation is necessary to make technology more attractive and easier to adopt by smallholder farmers. Their argument was largely that provision of a seemingly 'good' technology alone might not be sufficient to address the challenges of adoption and diffusion, hence service based approach would be more appealing.

> *'No, I abandoned Open Pollinated Varieties (OPVs). It is useless in terms of marketing. To market it is a big problem; because now seeds are hybrids and GMOs. Is a "normal" hybrids and GMO hybrids; so when you come with OPVs...'hai'...you don't stand a chance.' (R7)*

> *'(...) we offer free mentorship, we don't charge those farmers for mentoring, and then the other thing is technical support that they get. The production loan, the planning and execution of the production loan is also the best for us.' (R2)*
> *'(...) look, it mustn't just end with these tractors. We want to train people. We want to 'capacitate' people. We want to do skills development. We also want to monitor these technologies and processes.' (R5)*

A key observation in the data was that smallholder farmers, the target customers, will face increasing challenges due to climate change. The agri-technology providers noted the need to

CSATIs adoption to deal with climate change, yet also saw that smallholder farmers lack necessary knowledge, skills and financial capital to do so.

> *'I think [our CSATIs] is for both types of farmers, but some emerging and smallholder farmers lack the finance for the technology.' (R8)*

> *'(...)seed production requires high levels of management, and because I was starting from scratch with [farmers] who have never farmed with seed production, it takes time. With [farmers] who are long used to seed production, the process is not costly because you just give them seeds and leave them, and they will deliver the quality finished end products.' (R7)*

Regardless of the challenges facing smallholder farmers, some agri-technology providers identified providing CSATIs to smallholder farmers as a business opportunity. There would be costs in understanding smallholder farmers' needs and requirements. Nevertheless, smallholder farmers represented a potentially profitable mass market. Serving this segment would require a different approach, and one, which if successful, would increase technology adoption.

> *'I mean smallholder farmers for me, represent an access to a market, which is not tapped into. Because all our competitors are focusing on all the big commercial farmers, and neglect the smallholder farmers. But what they don't realize is that it is really a huge access to a market. Is huge market that is waiting to be tapped into, but you can't come there with standard rates and selling a tractor for so much as you would find in a price list. But if you look at the angle, via quantity, I mean we have got something like 8700 smallholder farmers in the province, so you are looking at that; an untapped market, so you really tailor something to be suitable for those kind of packages, you know developmental packages (...).' (R5)*

Respondents also noted several factors related to the value delivery component. First, agri-technology providers identified the importance of building relationships with their customers. Farmers value the service, probably because of the ability to ask questions and gain knowledge about the application, maintenance and/or marketing options of their produce. Respondents also noted that regular contact, which is costly, with customers is necessary to encourage their loyalty, which will affect the adoption and diffusion of CSATIs.

> *'There are lots of competitors. (...) what makes us tick is our feet on the farms. Our feet are physically on the farms, we have always believed that. That's the one factor, and the other is price; the customers goes for the cheapest fertilizers. (...) when you visit*

Chapter 4

their farms, they think you do care about their affairs, and that encourages them to come back to your business.' (R6)

'You must give people the service and you must be part of the people to help them, to grow them, etc. And I think on that level, [company name] is very close to the people.' (R10)

Second, the agri-technology providers largely agreed that access to rural smallholder farmers is difficult owing to their marginalised and isolated locations and underdeveloped infrastructures. New ways of reaching out to smallholder farmers included the use of additional channels, such as village depos. However, this service is costly for their businesses to maintain. It also raises the potential conflicts with other businesses.

'[Company name] brings us these seeds, and you know that we have depos all over the provinces, so we take these seeds to the depos. Farmers can go there, when they go buy maize meal, then they buy the seeds.' (R1)

'I don't think [having depots within villages] is something that stays. It is very difficult. Is something that we looked at, but I said we have got our branches, the [customers] comes for us.' (R9)

'(...)there are two things that play a role there. I have got a lot of guys that owns 'bakkies' and their business is to bring 10 people's maize here. That is his business. Now if I send my truck there, am going to cut his throat off. He is not going to be able to survive, you understand, that's the first thing. The second thing, we have got, depos, is not our depos but like our clients who buys mealie-meal from us, for instance. So the locals from there will deliver maize to them and they will store it for us and when we deliver mealie-meal we collect our maize from them. You see just because they are buying mealie-meal from us(...)we don't want to take business from smaller businesses.' (3)

Third, agri-technology providers noted that there was exploitation within the supply chain. For instance, government funds aimed at CSA were often absorbed by middlemen (e.g. tender-preneurs).

'...and that is where the problem starts for the input of costs of farmers. Those people who are tendering the farmers between the government, the buyers and our companies are making a lot of money. [tender-preneur] come and buy from us and that maize seed

was 350000 ZAR but the government pays [tender-preneur] 1.5 million ZAR. The margin is so high and you see, the whole structure is a problem.' (R10)

'Look, [we] can't say to [government] how they should handle their business. I know, is long I have been working on these things, government uses contractors. Even if they want papers, somebody must go and buy them papers; that's how they work. It will be better if they buy straight from [us], but [we] can't push.' (R7)

Fourth, good access to wider networks, including those related to policy, other suppliers and research was a requirement for agri-technology providers. It was important for key partners to understand the challenges their target customers faced. For instance, while the government may have adequate financial resources and good intentions in investment, farmers' lack appropriate farming skills, business mind-set, entrepreneurial and managerial skills may still jeopardise their prospects. One of the ways to address these could be through strategic partnerships among different stakeholders such as between private companies and/or researchers and government, to offer mentorship and training.

'The government have got resources, they have got money, they can offer these farmers training and everything, (...) we don't have money that we can offer training but the farmers that we work with are progressing far better than those working with government. [We] wish to help the government in mentoring those farmers to make sure they become sustainable in the system.'(R2)

'There was [research institute, government department, 4 private companies], all these stakeholders are helping farmers. They are bringing different things. This one brings seeds, this one brings fertilizers, this one brings agro-chemicals, etc., so that we can help the farmers. So we are working with all these stakeholders to help these entrepreneurs and farmers.' (R1)

'...and maybe that is one of the problem, because government help the guy and get the first crop on the ground and when they harvest and sell, money doesn't go to the farm. (...) maybe the farmers don't understand how it works, that you must put money back into the farm, and that you must go for the next crop and pay for it.' (R10)

In terms of value capture, smallholder farmers were not always able to afford CSATIs. Whilst credit provision may enhance the value offering, it appears that inflexibility in some business models, or rather their financial models, were an issue.

> *'...we sell our fertilizer on cash. We are not registered as a financial institution, because we have to pay for our fertilizers from our suppliers. So [fertilizer] is paid for and the [farmers] must pay; because it goes through as a small medium enterprise. So how do we cover our overheads if we give fertilizers on credit? We can't afford that. The risk is too high.' (R6)*

> *'Farmers have practiced a long time farming without fertilizer application and now they have milked the whole nutrients on the soil. To get better and improved yields, they need to get fertilizers but they don't always afford it.' (R8)*

A summary of the key results for the agri-technology providers, underlining the specific barriers and modifications that could enhance adoption and diffusion of CSATIs is illustrated in figure 6. We map these aspects onto the applicable component of the business model framework. The implications of these results are discussed in the following section.

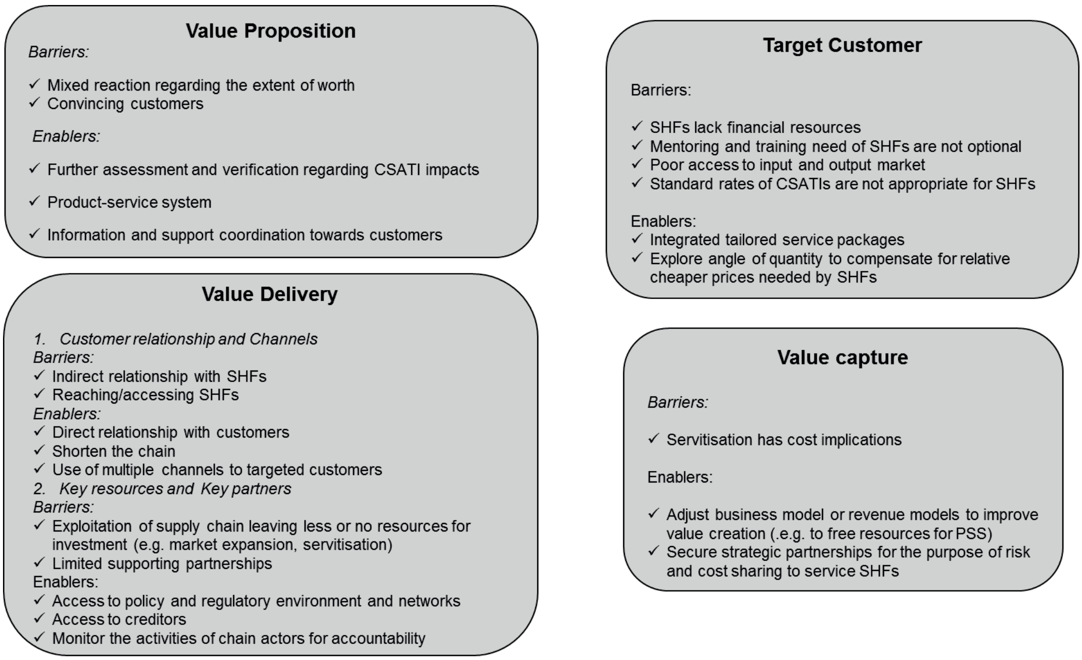

Figure 6: Critical issues for the BM*f*CSATIs based on agri-technology providers' perspective

5. Discussion

In order to explore the issues that affect the ability of business models used by agri-technology providers to diffuse CSATIs in the context of smallholder farmers, the theoretical framework (see figure 1) was explored with empirical data collected from agri-technology providers. First, we discuss the issues of *business models for CSATIs* that emerged from the empirical results. Second, we discuss the potential role of agri-technology companies in eradicating the barriers in the adoption of CSATIs by farmers.

5.1 Issues for business models for CSA technological innovations and previous research

Our results revealed that existing business models of the sampled agri-technology providers do not seem to be functioning optimally to diffuse CSATIs, particularly in targeting smallholder farmers. Previous research showed that relevant and clearly articulated value propositions would help overcome the sales and marketing difficulty of those innovations (Lin *et al.*, 2013; Long *et al.*, 2017). Our results revealed that with smallholder farmers within BoP, effective value propositions alone are not sufficient to enhance adoption. Agri-technology providers noted that product-service systems would enhance adoption, implying that additional services such as training, mentoring and credit need to accompany provision of relevant CSATIs. It was asserted that end-users understand benefits of their CSATIs and that in most cases the issue is affordability. This highlights the distinctiveness of the smallholder farmers within the BoP, as their core requirement goes beyond proof of impact noted in western contexts (Long *et al.*, 2017), and includes the need for access to credit.

Overall, these results are in line with previous research that business models should be understood as an instrument for innovation and a vital way for enhancing adoption of technological innovations (Evans *et al.*, 2017; Teece, 2010). Our results corroborate the importance of customer relationships and channels in effective technological innovation diffusion (Boons & Ludeke-Freund, 2013; Gabriel & Kirkwood, 2016). Whilst some of the respondents emphasized the risk and difficulty of reaching smallholder farmers in remote rural areas, some agri-technology providers noted this as an opportunity to expand their businesses. However, they acknowledged their current offering need to be adapted to suit the need of these farmers.

The second critical issue, also part of the value delivery component, concerns the relationship with targeted customers and how they market themselves (Gabriel & Kirkwood, 2016; Ver Loren van Themaat *et al.*, 2013). According to Ver Loren van Themaat *et al.* (2013) companies need to tailor their products and services to ensure that they are acceptable within the contexts of specific customers. Whilst our respondents recognised this factor, some reported to have direct relationships with their customers whereas others reported indirect relationships. In the former scenario, the respondents could rely on word of mouth. However, the latter scenario often meant higher costs, due to the high mark-ups that government contractors (i.e. tender-preneurs) charge for their services, due to the use of more sophisticated and official procurement systems. According to respondents, this is problematic and impedes interventions aimed at enhancing technology adoption. This is a critical issue to the BoP context where government intervention is often a key driver in CSATIs adoption. This is a particular challenge in South Africa where tendering systems are often used. Therefore, to enhance CSATIs adoption by smallholder farmers, optimal business models of agri-technology providers need to be backed by high level monitoring of supply chain activities to avoid exploitations.

The third key issue noted was access to key resources (Demil & Lecocq, 2010; Ver Loren van Themaat *et al.*, 2013). Financial resources are needed to train and equip targeted customers with modern farm management and technical skills. The resources and support services needed by the farmers vary according to their socio-economic circumstances and their type of enterprise. Access to funding to provide such services is not always easy. This is typical and concurs with previous research, which points out that sustainable innovations need financial and supportive regulatory protection from external stakeholders during their initial stages (Ceschin, 2013; Gabriel & Kirkwood, 2016; Long *et al.*, 2017). Furthermore, literature recognizes the importance of provision of specific types of support (Gray *et al.*, 2014), by those who intervene in order to eliminate and reduce the barriers that smallholder farmers in adopting the CSATIs.

The fourth issue was related to problems in accessing, fostering and sustaining some key partnerships and networks needed to enhance agri-technology providers' capabilities and resource base to create and capture value (Ceschin, 2013; Voelpel *et al.*, 2004; Wirtz *et al.*, 2016). Failure to forge or sustain these partnership was considered a critical to pursue service-based approach aspired by the agri-technology providers.

The fifth issue raised by our respondents in relation to the value proposition, was the need for low margins especially in order to cater for smallholder farmers. This issue is highlighted by previous research indicating that lower initial margins may facilitate competition with reputable companies (Chesbrough, 2010; Long *et al.*, 2017). Some of the CSATIs were felt to be too expensive for smallholder farmers, suggesting that the margins are too high. The solution here is to explore how agri-technology providers can make money while their products are affordable to smallholder farmers. These results are in accord with Teece (2010) that price systems are critical because customers are inclined to buy only if the price is less than the utility yielded and producers will supply if price is at or above all costs including return to capital. This suggests for smallholder farmers to be successfully served, that a high number of products must be sold on a limited margin.

5.2 The potential of the agri-technology providers to eradicate the barriers to adoption of CSATIs by farmers.

Smallholder farmers need access to long-term production credit and finance to buy CSATIs and/or pay for related services. Our data revealed that agri-technology providers deliver a range of services to smallholder farmers which include provision of short to medium-term credit. However, provision of relatively short-term credit is often inadequate for smallholder farmers in BoP context. Long-term credit may be needed to enhance adoption by smallholder farmers.

We found that the government may buy and/or pay agri-technology providers for most CSATIs on behalf of the farmers. This implies that government intervention is a driver to CSATI adoption by smallholder farmers. Although agri-technology providers concurred production credit is important in eradicating some barriers to adoption of CSATIs, some argue the risks are too high to bear (in terms of debt), especially when dealing with smallholder farmers. Some respondents emphasized that it is better to play it by the book when lending money to farmers. This would mean that collateral will be required for production credit loan, thus excluding many smallholder farmers. These results corroborate previous research suggesting that whilst product-service system innovation is a promising business model, it brings along noteworthy challenges for companies, customers and regulatory environments (Ceschin, 2013). The reason for this is that companies often find product-service system strategies complicated relative to traditional ways of delivering products alone (Ceschin, 2013; Manzini & Vezzoli, 2002).

In some instances, we found that agri-technology providers offered production loans for most variable inputs, mentorship and training to farmers, conditional to them having basic infrastructures (e.g. tractors and irrigation waters). In the case of our research, the government is often the provider of such infrastructures. This again suggests that government intervention in a multi-actor based business model is a driver that can enable farmers to buy and/or pay for CSATIs.

Our results revealed that agri-technology providers address smallholder farmers' problems such as lack of access to input markets, lack of access to storage and grinding technologies and lack of output markets, to a certain extent. 'Engagement', 'Integrated packages' and 'Sale and procurement' business models are trying to solve customers' problems rather than merely waiting for those that can afford to come and buy from technology providers, for various reasons. For instance, milling companies in particular indicated that they are inclined to help smallholder farmers get access to technologies. Respondents noted that if the local smallholder farmers can produce enough quality produce, this safeguards their own supply of raw material relatively cheaply in the long-term. The reasoning of the respondents can be seen to be both an economic and strategic driver behind their business logics' in that they 'want to feed the cow they milk'. Nevertheless, the implication of this strategy is that these agri-technology providers have the potential to drive adoption of CSATIs if farmers' obstacles are lack of input and output markets. However, where financial constrains are prevalent, collaboration between government and agri-technology providers would still be required to safeguard adequate adoption of CSATIs.

The results highlight that technology alone does not fully address the challenges that farmers are facing. Smallholder farmers in particular require additional support. Our results highlight the use of product-service system strategies. By offering services such as soil analysis, maintenance plans, structured training and mentorship, these agri-technology providers' services can align to the principles of CSA. For example, one of the respondent noted that they offer their customers a 2 years' maintenance plan, indicating that this service can help improve the use of technologies, enhancing agricultural productivity and the efficient use of inputs (enhancing output and reducing GHG emissions). This kind of service shows some major source of advantage with a product-service system strategy, including prolonging the life of capital (existing tractors through better care of these technologies). Life extension of the products, means, however, that reduced demand for replacement capital and additional sales will be lower (Brouillat, 2009; Kastalli & Van Looy, 2013), meaning lesser resources and materials that would be needed when new tractors are designed and manufactured. However, this service (i.e. tractor maintenance) may to some degree, substitute product (i.e. new tractors) (Siggelkow, 2002).

5.3 Implications and adaptations to the agri-technology providers' business models needed to enhance adoption of CSATIs by smallholder farmers

Having discussed the key issues for business models for CSATIs and the potential role of agri-technology providers in enhancing diffusion of CSATIs, next we discuss what sort of adjustments or innovations of the identified business models would boost the diffusion rates of CSATIs.

1. *Reconsider Procurement System*: a large share of the financial resources from government aimed to enhance smallholder farmers' adoption of CSATIs, benefit other chain actors (e.g. tender-preneurs). The government's popular approach of procuring goods and services through tender system exacerbates the challenges regarding the adoption of CSATIs. Respondents argued that tender-preneuring as a procurement method is susceptible to corruption and should be avoided. This is due to the exorbitant mark-ups charged by the tender-preneurs to government, thereby inflating government costs of interventions. These findings tally with Mantzaris (2014) who indicated that procurement transactions are easy targets, particularly in South Africa, when it comes to fraud and corruption within public sector organisations. Reconsideration of procurement system could also imply that monitoring and evaluation be intensified to prevent irregularities noted by the respondents.
2. *Enlarge partnerships and collaboration:* the results reiterate the need for collaboration with government in implementing product-service offerings that have the prospect of enhancing the adoption of CSATIs. To implement CSA adequately, smallholder farmers need a package of CSATIs and it appears that agri-technology providers, although willing to partake in the services, are not yet ready to bear all the costs.

Our study has some limitations. Our analysis is based on a small study population of 10 agri-technology providers. We also recognize the drawbacks of using the snowball approach to identify respondents. Where possible we have corroborated the referrals with internet searches to identify the agri-technology company and/or respondents. In this study, our focus was on the smallholder farmers market. However, considering that South African agriculture is dual in nature, understanding the barriers faced when targeting emerging to large commercial farmers may add an additional layer of insights to future studies, and thereby provide a holistic picture concerning uptake of CSATIs. Lastly, we concede that the business model does not permit for an all-inclusive detailed understanding of how these agri-technology providers' businesses run. Certainly, there are other factors such as technology, ease of access, novelty, adaptability and self-drive, that are essential characteristics of agri-preneurial activity; these are not necessarily included in business model frameworks. Investigating these additional factors may add an additional layer of insights to future research. Furthermore, future studies should seek to validate the above results employing a larger samples covering other provinces of South Africa and other countries.

6. Conclusion

This study has explored and highlighted key issues for BM*f*CSATIs, by identifying barriers and enabling factors that could enhance the adoption and diffusion of CSATIs. By pinpointing where in the business models of agri-technology providers these barriers and factors occur, we show how business models influences the adoption and diffusion of technological innovations in BoP contexts. We identified the shortcomings of the businesses models, and suggested business model innovations.

Seeing that BM*f*CSATIs are non-optimal, it is conceivable to consider them to be one barrier to the uptake of CSATIs within smallholder farming at the BoP. Our study revealed that smallholder farmers have the potential to offer valuable opportunities for agri-technology providers that target them; however, smallholder farmers' characteristics make them a difficult market to target. Nevertheless, if agri-technology providers that provide CSATIs with or without limited product-service system are able to advance to full product-service system and expand to accommodate smallholder farmers through integrated services, these could help to overcome some of the aforementioned business model shortcomings. Thus, if smallholder farmers are serviced with regard to credit provision, more structured training and mentorship or leniency towards their realities, then they may be motivated to be optimistic about their potential to contribute to the uptake of CSATIs within smallholder agriculture. This highlights a role for business model innovation, which may require additional understanding of the barriers that agri-technology companies face while targeting their market.

Through this research we have contributed to broader literature on business models and their associations with sustainable innovations. Although our empirical findings were largely consistent with key factors identified within literature, two additional issues peculiar to BoP contexts where identified. First, literature on western context indicated that relevant and clearly articulated value proposition concerning CSATIs would overcome their sales and marketing difficulties, however our results indicated that within BoP, provision of 'good' CSATIs alone is not sufficient to enhance adoption. Product-service system could be a business model innovation that would help to overcome barriers to CSATIs adoption. Second, our results indicated that the core requirement of smallholder farmers within the BoP goes beyond proof of impact (as it is the case in western contexts), but include a need for production credit. The practical relevance of this study was to provide an input for future agri-technology providers concentrating on the smallholder farmers market or those intending to expand their market to cater smallholder farmers particularly with regard to CSATIs. Furthermore, for policy makers aiming to enhance adoption of CSATIs, the results of this study could serve as a first step to identify areas of intervention.

5

Enhancing the adoption of climate-smart technologies using public-private partnerships: Lessons from the WEMA case in South Africa

This chapter is based on: Mmapatla Precious Senyolo, Thomas B. Long, and Onno Omta. "Enhancing the adoption of climate-smart technologies using public-private partnerships: Lessons from the WEMA case in South Africa". Under-review with the *International Food and Agribusiness Management Review Journal*.

CHAPTER 5

1. Introduction

Climate change would exacerbate developmental challenges in Africa. Agricultural production may be significantly impacted due to changes in rainfall patterns, increases in temperature and variations in the frequency and intensity of extreme climatic events such as droughts and floods (Brida *et al.*, 2013; Elum *et al.*, 2017; Hellin *et al.*, 2012; Khatri-Chhetri *et al.*, 2017; Lobell *et al.*, 2011; Lobell *et al.*, 2012; Ziervogel *et al.*, 2010). Some of the impacts of climate change on agriculture may include changes in crop cultivation, agriculture biodiversity, decreases in input use efficiency, increased prevalence of pests and diseases, and disruption to markets (Khatri-Chhetri *et al.*, 2017; Lipper *et al.*, 2014; Norton, 2014). South Africa, like many African countries, has been identified as being especially vulnerable to the impacts of climate change (DEA, 2011; Elum *et al.*, 2017), partly because the agricultural sector is a major employer in South Africa. For these reasons, the country needs supportive policies to develop and implement technological innovations to enhance climate change adaptation among farmers, and particularly smallholder farmers (Elum *et al.*, 2017; Senyolo *et al.*, 2018). Smallholder farmers are often less able to adapt to climate change as they often lack the means to improve their adaptive capacity due to factors such as lack of credit, limited access to input and output markets and no insurance to hedge against climatic risks (Elum *et al.*, 2017). Yet, the adverse effects of climate change demand that they adapt to these changes in order to safeguard their food and livelihood security (Andrieu *et al.*, 2017; Elum *et al.*, 2017; Maponya & Mpandeli, 2012b; Mullins *et al.*, 2018).

Numerous potential adaptation options to reduce climatic risks exist (Khatri-Chhetri *et al.*, 2017; Makate *et al.*, 2019). Climate smart agriculture (CSA) is recognized as one innovative approach to effectively achieve the developmental goals of vulnerable populations (e.g. smallholder farmers) dependent on agriculture (Partey *et al.*, 2018). For instance, CSA is about transforming and reorienting agricultural systems, with a focus on developing resilient food production systems that lead to food and income security under climatic change and variability (Khatri-Chhetri *et al.*, 2017; Lipper *et al.*, 2014). The CSA concept is already embedded in many indigenous practices, tools and approaches that have helped farmers produce food in the face of past climate change and variability. Still, advances in CSA research has drove development and dissemination of somewhat new approaches, tools and policies such as high yielding and drought resistant seeds, agricultural insurance, climate information systems, solar-powered drip irrigation systems, integrated tree-crop-livestock systems, precision agriculture and infield rainwater harvesting (Mapfumo *et al.*, 2014; Partey *et al.*, 2018; Senyolo *et al.*, 2018).

There is no doubt that CSA technological innovations (hereafter CSATIs, including technologies, practices and services) individually or in combination, have the potential to reduce the impact of climate change on agriculture (Bedmar Villanueva *et al.*, 2016; Khatri-Chhetri *et al.*, 2017; Senyolo *et al.*, 2018). However, their current rate of adoption and diffusion is low due to several barriers encountered by both the end-users (i.e. farmers) and technology providers (Asfaw *et al.*, 2016; Khatri-Chhetri *et al.*, 2017; Long *et al.*, 2017; Partey *et al.*, 2018). Factors, such as affordability, local availability, access to production credit, size of land, preferences and attitudes, gender and marital status of the farmers, as well as related training and demonstration affect farmers' adoption decisions. Agri-technology providers also experience difficulties and barriers. Provision of technology alone does not fully address the challenges that smallholder farmers are facing, as they require additional support. Thus smallholder farmers within the base-of-the-pyramid (BoP) often require production credit in addition to proof of impact of some of the promoted CSATIs.

To help overcome some of the barriers hindering the diffusion of CSATIs, numerous initiatives have been implemented. For instance, government agencies and agricultural research institutions have conducted different types of pilot programmes and projects to demonstrate the benefits of CSA by highlighting how CSA can deliver 'triple-win' outcomes (Cavanagh *et al.*, 2017). The 'triple win' outcomes suggests that CSA approach pursues the triple objectives of sustainably increasing productivity and incomes, adapting to climate change and reducing greenhouse gas emissions where possible (FAO, 2010b). As a result, this does not imply that every practice and/or technology applied in every location should produce "triple wins", instead the CSA approach seeks to reduce trade-offs and foster synergies by taking these objectives into consideration to inform decisions from the local to the global scales and over short and long time horizons, in order to derive locally-acceptable solutions. Likewise, the government and the private sector have joined forces in public-private-partnerships (PPPs) to intervene with the aim to enhance adoption and diffusion of agricultural technologies under climate change related risks within smallholder agriculture.

PPPs started in the 1990s and describe the provision of public assets and services through the participation of the government, the private sector and the consumers (Grimsey & Lewis, 2005). These PPPs are a popular approach for several reasons which include achieving improved value for money and sharing of risks (Cui et al., 2018; Grimsey & Lewis, 2005). In agricultural research and development, PPPs are increasingly considered an effective way of conducting advanced research, commercializing new technologies, and deploying new products for the benefit of small-scale, resource-poor farmers; food insecure consumers; and other marginalized groups in developing countries (Spielman et al., 2007). According to (Grimsey & Lewis, 2005), PPPs are well-established practices in countries such as the UK, Australia, The Netherlands, South Africa, Canada and Japan. Theoretically, PPPs are suitable to create the innovations necessary to promote the adoption and diffusion of technologies, yet in practice they are subject to several constrains. Consequently, barriers which can be described in terms of market failure, institutional constraints and systematic weaknesses tend to impede the otherwise smooth process of exchanging and using knowledge necessary to the innovation process (Spielman et al., 2007).

An example of a PPP formed with the aim to enhance the adoption and diffusion of agricultural technologies under climate change related risks within smallholder agriculture is *the WEMA initiative*, a PPP with the objective to improve food security and rural livelihoods among smallholder maize producers in sub-Saharan Africa. The project seeks to develop and disseminate seed technologies which are drought-tolerant and insect-pest-protected (Edge *et al.*, 2018). We argue that while PPP initiatives like WEMA have the potential to facilitate market access for, and technology development and dissemination to smallholder farmers (Bitzer & Bijman, 2014; Edge *et al.*, 2018; Ponnusamy, 2013), their impact and efficacy can be limited due to certain barriers (Bitzer & Bijman, 2014; Edge *et al.*, 2018; Ezezika & Daar, 2012; Ponnusamy, 2013). For instance, different perspectives on the challenges to and possibilities for innovation possessed by different actors within a partnership can be challenging to reconcile and combine due to cognitive, information and managerial gaps between actors involved (Bitzer & Bijman, 2014; Klerkx & Leeuwis, 2008). Also, power, knowledge, institutional or political strength and negotiation skills asymmetries among actors can complicate communication process and also influence and skew the innovation process in favour of the terms and priorities of the more powerful actors (Bitzer & Bijman, 2014; Bode *et al.*, 2008; Murphy *et al.*, 2012).

Against this background, the aim of this paper is to examine the role of the WEMA project in enhancing technology adoption by South African smallholder farmers in the context of moisture stress and water scarcity. By exploring the WEMA case, we seek to examine how PPPs can enhance technology adoption, and how hindrances faced by the partnership in enhancing technology adoption can be overcome and opportunities leveraged. The study seeks to highlight whether the WEMA initiative enhanced technology adoption by smallholder farmers, and what factors enabled and/or constrained the WEMA PPP. In doing so, the study focuses on 4 aspects: (1) The characterisation of the WEMA PPP, (2) the development of the WEMA PPP, (3) Its management and operations, (4) and its performance and its contribution to development.

2. Literature review

Public-private partnerships

Partnerships between farmers, businesses, governments, NGOs and/or multilateral agencies are prevalent in agricultural development. PPPs help to realize innovation and sustainability goals that organisations acting alone would not otherwise be able to achieve (Bitzer & Bijman, 2014; Ponnusamy, 2013; Spielman *et al.*, 2007). For instance, they can facilitate smallholder farmers' access to seed varieties with resistance to insect pests or drought-tolerant varieties (Edge *et al.*, 2018; Ezezika & Daar, 2012) According to Ponnusamy (2013) a PPP is a well-used strategy to realise public services and infrastructure goals in agriculture, education, science and technology, health, infrastructure development and extension. Generally, the motive behind the development of a PPP is a shortage of human resources, facilities and time; and within agriculture, the essence of PPP is understood in terms of a shared mechanism for resources, markets, inputs, risks, technologies and benefits (Ponnusamy, 2013). Another reason cited for the adoption of PPP is related to the failure of civil servants to effectively deliver and maintain public services, for instance, due to corruption associated with public procurement (Otairu *et al.*, 2014). PPPs are also recognised for their ability to strengthen project monitoring as well as to ensure greater accountability (Fombad, 2013; Ismail, 2013), which could be necessary to safeguard effectiveness of government interventions aimed at enhancing technology adoption and diffusion.

The importance of public-private partnerships in the agricultural sector

Global climate change as well as land and water scarcity are emerging as key challenges to agricultural sustainability. Climate impacts are compounded by market related failures, weak institutions, inappropriate policies and low use of technologies (AATF, 2014). To tackle these kinds of challenges, multidisciplinary and multi-institutional efforts forging partnerships across institutions and sectors, are necessary (Kpadonou *et al.*, 2017; Ponnusamy, 2013). Smallholder distress comes from a mix of challenges, and therefore solutions will depend on a combination of both technological and non-technological interventions (AATF, 2014). Examples of technological interventions include replenishment of soil nutrients, injection of mechanization, better post-harvest management, better agronomic practices and improved seed varieties. Non-technological interventions include enabling policies to come to efficient and adequate markets, sufficient government support, strong agricultural finance systems leading to adequate funding, capable institutions, such as extension services and the development of effective PPPs (AATF, 2014). Other reasons cited for the promotion of innovative partnerships that bring together business, government and civil society actors to improve productivity and to drive growth within agriculture and food sectors around the world, are limited government resources and expertise (FAO, 2016). In general, each partnership is designed to address a specific national problem, and related economic, social and/or environmental issues.

3. Research Approach

Since the aim of this study was to explore and highlight challenges identified within the WEMA project in South Africa, the study focused on the following main research topics:

1. Characterization of the PPP arrangement.
2. Development of the PPP arrangement.
3. Management and operations.
4. Performance and development outcomes.
5. And what factors enable and/or constrain the arrangement.

In order to understand the aforementioned topics within the context of our research, we explored the literature and the publicly available WEMA project documents, and corroborated this with data from informants associated with the WEMA project in South Africa. The WEMA partnership is coordinated by the African Agricultural Technology Foundation (AATF), drawing on its unique experience in PPP management, technology stewardship and project management. The AATF is working with the National Research Systems (NARS) in Kenya, Mozambique, South Africa, Tanzania and Uganda; the International Maize and Wheat Improvement Centre (CYMMIT); Monsanto. The Bill & Melinda Gates Foundation, the Howard G. Buffett Foundation and the USAID are funders of the WEMA initiative. In South Africa, the project is co-ordinated by the Agricultural Research Council (ARC). The NARS, farmers' groups and seed companies participating in the WEMA project, contribute their expertise in breeding, field testing, seed multiplication and distribution. CYMMIT provide high yielding maize varieties that are adapted to African conditions and expertise in conventional breeding and testing for drought tolerance. Monsanto, a private agricultural company now part of Bayer, is contributing maize varieties from its global proprietary collection, drought-tolerant and insect protection genes, as well as its expertise in agricultural research and product development. Each of the WEMA partners contributes its technology, time and expertise to the project. Furthermore, participation by farmers' groups and government in the WEMA project is presumed to strengthen African capacities in crop breeding and biosafety.

Smallholder farmers' adoption processes and decisions are generally known to be multifaceted and hindered by several factors including biophysical and socio-economic constraints, barriers in the political process and institutional environment within which they operate. Therefore, in many cases interventions are necessary to help them overcome these adoption barriers. For that reason, public or private interventions with intentions to enhance the adoption by assisting smallholder farmers to overcome the adoption barriers can be seen as a relevant case (Patton, 2002) to understand the complexity of the adoption and diffusion processes. Since previous research showed that a PPP is an approach that offers the opportunity for public and private partners to combine efforts and resources in their interventions, resulting in better economic conditions and livelihood of target population (Edge *et al.*, 2018; Ponnusamy, 2013), we sought a case where interventions to enhance technology adoption by smallholder farmers was a result of PPP. During the time of our data collection, the WEMA case in South Africa offered a particularly interesting example to study how interventions to enhance adoption and diffusion of CSA technologies such as drought-tolerant seeds work in practice and the challenges that are likely to be encountered.

Drought is one of the major causes of reduced maize production and food insecurity, especially in sub-Saharan Africa, where agriculture is largely rain fed (Lunduka *et al.*, 2017). Projected changes in precipitation and increases in temperatures are likely to have implications for maize production, and consequently, food security and livelihoods of smallholder farmers (Cairns *et al.*, 2013; Cairns *et al.*, 2012; Lobell *et al.*, 2011). Therefore, to safeguard national food security and economic stability, adaptation to such climatic changes is essential. Development of the drought-tolerant maize varieties is recognized as one of the adaptation strategies in store to sustaining maize production (Lunduka *et al.*, 2017). While the development of drought-tolerant maize varieties continued to be the intention of breeding programmes and research institutes across the globe (Bänziger *et al.*, 2006), the majority of farmers in sub-Saharan Africa (SSA) still use traditional and unimproved low-yielding seed varieties (Langyintuo *et al.*, 2010). For instance, although South Africa has the most-developed formal seed system in Africa, the system is not necessarily best suited to provide smallholder resource-poor farmers with appropriate and affordable seeds (Edge *et al.*, 2018; Marechera *et al.*, 2016); to address this, a tailor-made intervention is necessary. Availability of good quality seeds that are resistant to heat and drought is essential to increase crop production and productivity. Factors such as decreasing soil fertility, a shortage of arable land, and moisture stress are likely to worsen because of high temperatures and erratic rainfalls related to climate change (Asfaw *et al.*, 2016; Marechera *et al.*, 2016; Phiri & Saka, 2008; Tripp & Rohrbach, 2001).

Data collection and analysis

A qualitative research design was chosen due to its ability to permit the researcher to value and capture the in-depth nature of a phenomenon or behaviour (Taylor & Bogdan, 1998). We adopted the inductive qualitative case study approach to gather data from key informants. A mix of data sources was used to increase validity. We collected secondary data by reviewing academic articles, news articles and publicly available documents on the WEMA project. We also conducted semi-structured face-to-face interviews with 10 individuals. This included 5 key informants (representing the public and the private sectors) to gain an understanding of how the WEMA project evolved in practice in South Africa, including the outcomes as well as the challenges experienced. These key informants included the WEMA South Africa coordinator, 2 officials from the provincial department of agriculture, 1 university researcher, and 1 manager from 1 of the 4 local seed companies that were licensed to sell the WEMA products. The other 5 semi-structured interviews were conducted with 5 out of the 14 farmers that were sub-contracted by the licensed local seed companies to plant and produce WEMA seeds to be sold to smallholder farmers. Furthermore, a focus group discussion was held with 9 farmers participating in the WEMA project at Mokaba village. These respondents, together helped to provide insights from different viewpoints as they served various functions within the WEMA project, and gave different perspectives. This enabled triangulation of the information among different respondents. Interviewees were identified first by making a list of key individuals associated with the project. This list was then populated further through snowball sampling by engaging with the partners in the project and stakeholder informants who were familiar with the WEMA project. For a brief outline of the respondents for this study see table 1.

Table 1: Respondents and brief outline of their role in WEMA project

No	Field of study	Responsibilities within organisation or farm	Roles within WEMA project
KI1	Plant breeding, biotechnology and genetics as well as crop science and agricultural biotechnology	Senior Research Manager in charge of the Agricultural Research Council (ARC), Institute of Grain Crops	Regional coordinator and WEMA project leader in South Africa. Also involved in research, fields and on-farm trials and demonstrations of the WEMA products, both hybrids and open pollinated varieties. Furthermore, engaged to give advice to the licensed seed companies and to monitor if they deliver on their commitments
KI2	Agriculture: Agronomy	Lecturing, supervision of student projects. Conduct research on crop rotation, indigenous vegetables, different varieties of maize cultivars (e.g. WEMA)	Conduct research on some of the WEMA materials with farmers and/or in farmers' fields to test them and compare them with alternative varieties that are already recommended and used in farmers' regions.
KI3	Agricultural Economics	Manager of the company which produces and sells certified seeds, who work closely with	Licensed to produce and market certified WEMA seeds, both hybrids and OPVs. The

		farmers, mostly under contract arrangements.	production is done through sub-contracting of farmers.
KI4	Plant Breeding	Managing Scientific research within research section of Department of Agriculture	Involved in research, field trials and demonstrations of WEMA products. Also responsible for awareness raising regarding WEMA seeds, both hybrids and OPVs
KI5	Plant Science: Agronomy	Manager, Agronomy and Seed Multiplication, Department of Agriculture	Involved in Projects of community based seed production.
IF1-IF5	Secondary and Post-secondary education with background in agriculture	Makes all the major decisions regarding what crops to plant at any given time and season in accordance with various contracts or independently.	Sub-contracted by the licensed company to produce on its behalf the certified WEMA seeds.

KI=key informant and IF= individual farmer

Individual farmers IF1 through IF5 have practical experience in agriculture. Some of them were considered very successful as land reform beneficiaries and/or are emerging to become commercial farmers. For example, IF4 was even crowned Limpopo Female Farmer Champion during the annual provincial female entrepreneur of the year awards in Polokwane in 2016. To analyse the empirical data, several steps were taken. First, the interview data were transcribed, and during this process, key initial observations like the WEMA project setting and partners, as well as topics that were relevant, were noted. The analysis was performed by reading through the transcripts iteratively, identifying relevant points related to our research questions, possible trends and organizing them into major themes. The results were critically analysed to construct a comprehensive narrative on barriers that were identified within the WEMA project that were impacting its efficacy and impact on the targeted output (technology deployment and adoption) and beneficiaries (i.e. smallholder farmers).

4. **Results**

Characterization of the WEMA arrangement

The African Agricultural Technology Foundation (AATF) mandate within the WEMA project is actually to negotiate and access proprietary technologies to smallholder African farmers' royalty-free, in order to make the technologies affordable. Accordingly, the AAFT is the major grantee of the project in terms of funding. The first five years (i.e. 2008-2012) of the project were funded by the Bill and Melinda Gates Foundation and the Howard G Buffett Foundation.

The second phase (i.e. 2013-2017) was funded by USAID. Monsanto donated the drought traits as well as the Bt[6] traits to the project. The company also donated part of their germplasm and assisted with some of their advance breeding tools. The International Maize and Wheat Improvement Center (CIMMYT), which is a non-profit research and training institution dedicated to maize and wheat science, have germplasms or maize lines that are tolerant to biotic and abiotic stresses. The institution targets critical challenges including food insecurity and malnutrition, climate change and environmental degradation.

There are five countries from the East and Southern African region participating in WEMA project through their respective National Agricultural Research Systems (NARS), namely: Kenya, Uganda, Tanzania, Mozambique and South Africa. In South Africa, the NARS in question is the Agricultural Research Council (ARC). Therefore, within the WEMA partnership, ARC developed varieties, to ensure that they are taken up by seed companies, whereby the AATF then provided sub-licenses to each seed company so that they could produce and market the seeds.

In order to ensure that smallholder farmers get access to those improved WEMA varieties, the WEMA PPP saw the need to stimulate private-sector involvement to tap into private seed companies' abilities to invest in production and selling of those varieties. This was felt important as the ultimate goal of WEMA partnership was also to deploy rather than only develop. All seed companies were targeted to produce and market WEMA products. Therefore, in order to get buy-in all local seed companies were invited to see the WEMA varieties in Potchefstroom and apply for the basic material to multiply and market the seeds. The seed companies that came forth to produce and market the WEMA varieties were Capstone, Advance Seed, Seed Co and Jermart Seed.

Development of the PPP (WEMA) arrangements

The WEMA partnership officially started operating in 2008. However, the negotiation of the various WEMA partners to formalize the idea into a funded project started in 2007. The AATF with its notable leadership and unique experience in PPP management, became a central player in WEMA in 2007 and at the request of Monsanto, took the lead in preparing an investment plan to the Bill and Melinda Gates Foundation. The AATF went further to extent its invitation to CYMMIT to participate in WEMA in 2007. CYMMIT was invited to the partnership to provide high-yielding maize varieties that are adapted to African conditions and for their expertise in conventional breeding and testing for drought tolerance. For instance, by 2002, CYMMIT had managed to develop maize hybrids with yields under drought conditions

[6] Bacillus thuringiensis (Bt) is a naturally occurring soil bacterium that Monsanto used in some of its corn and cotton seed products to provide protection from damaging insects.

averaging 20% above local hybrids not improved through stress breeding. Given CYMMIT's possible progress at low cost through the use of conventional breeding methods in Africa, there was a question as to why anyone should employ the more expensive approach of genetic engineering. However, a counter response is that genetic engineering offers the potential to provide improved drought tolerance to the already improved CYMMIT hybrids. Nonetheless, whether the scientifically justified approach of employing genetic engineering to develop drought-tolerant maize would be sufficient to overcome the potential political barriers, remained unclear to CYMMIT in 2007.

Considering the role of policy makers in food security and climate change adaptation in developing countries, it was necessary to engage the governments of the WEMA participating countries. Similarly, government support and the political will to introduce biotechnology for smallholder farmers in Africa were understood as critical components for the success of the WEMA project. Therefore, the NARS of the 5 WEMA participating countries which were supportive of developing, biosafety laws for the commercial cultivation of genetically modified crops agreed to join the partnership. The NARS in those countries had no experience with the unique challenges of integrating biotechnology into their programs. However, in 2007 they indicated their desire to learn and their willingness to try. Bill and Melinda Gates Foundation officers identified drought tolerance as one of the most important crop improvement goals for helping smallholder farmers in Africa. Although the foundation in 2007 did not have a specific strategy to embrace genetically engineered crops for Africa, they had established a platform to support crop improvement projects that used technologies most likely to address the effects of drought in Africa. For this reason, they were inclined to fund an initiative like the WEMA partnership. Table 2 gives a summarised timeline of events concerning WEMA PPP project.

Table 2: Timeline of events regarding WEMA PPP

Events	**2007**	**2008-2012**	**2013-2017**
Negotiation of partners to formalize the idea of WEMA PPP into a funded project started	X		
Monsanto requests the AATF to become the driver of the proposed WEMA PPP	X		
The AATF accepted the request and became central player in WEMA PPP formulation and preparing an investment plan for the Bill and Melinda Gates Foundation	X		
The AATF invited CYMMIT to participate in WEMA PPP	X		
The NARS of the 5 WEMA participating countries also indicated the desire to be part of the WEMA PPP	X		

Bill and Melinda Gates Foundation and the Howard G. Buffett Foundation funded the first phase of WEMA PPP		X	
WEMA PPP was formed and the phase one project started. Main activities of the first phase included bringing together parties from participating countries to work together in building the necessary scientific testing, regulatory procedures and protocols for the evaluation of maize varieties in the project within each of the five participating countries. Thus, activities included: collaboration agreements signed, WEMA project launched, formation of work teams and harmonisation of the work plans, and identification and development of trial sites, WEMA breeding and testing programme, Awareness campaign, study tours, strengthening capacity to deliver drought-tolerant maize and stakeholders rate WEMA.		X	
The USAID came on board and funded the second phase of WEMA PPP			X
WEMA PPP continued and the project moved to phase two. The following activities continued: field trials, continued, Awareness raising, application for regulatory approvals, launching of the approved conventional hybrids and application of the environmental release for the triple-stacked product.			X

Management and operations

The WEMA partners organized themselves into global and in-country teams. They were of the opinion that a good management leadership structure was necessary to manage the complexity, facilitate the cross-functional connectivity, while keeping everyone focused on the ultimate goal of the project: farmers need to purchase and plant the seeds and get yield advantages to create a scalable and sustainable adoption of the technology. To reach this goal, within the WEMA project, there was a Product Development Team (PDT), which was responsible for setting the technical milestones and to conduct the variety development. There was also a Product Deployment Team (DEPT) which was tasked to develop the project commercialisation strategies, to guide certified seed production, promotion, distribution, as well as to stimulate private-sector involvement. Moreover, since WEMA partners used two approaches in terms of developing the varieties (i.e. conventional and genetic engineering), they had a Regulatory Team (RT) which task was to obtain necessary regulatory approval in the in WEMA participating countries. The WEMA project also had a Communication and Outreach Team (COT), responsible for deployment and implementation of the communication outreach, strategy and planning, and also capacity building. The fifth and last team was the Legal and License Team (LLT), responsible for drawing up legal and licensing documents.

Each WEMA functional team had specific performance goals. For instance, the PDT had tangible metrics to evaluate its success. This included, counting the number of rows planted per year, the number of new hybrids in national performance testing, and the number of new hybrids registered for commercial release and comparing the yield data on their newest hybrids to the best alternative on the market. The RT measured its progress based on the number of applications submitted and approved as well as the project's compliance with regulations for monitoring field trials. The DEPT measured its achievements by indicators, such as number of seed companies licensed, amount of basic and commercial seeds produced, brand awareness, and the amount of seeds sold and planted by smallholder farmers. The LLT measured its success based on the number of seed companies and products licensed. The COT was able to monitor its success by tracking media coverage and cataloguing interactions with various stakeholders.

Performance and development outcomes

The final product of the WEMA partnership was intended to be the seed varieties with enhanced drought tolerance as well as insect protection. As of 2017, WEMA had more than 60 conventional drought-tolerant white maize hybrids registered across the five WEMA countries. These hybrids were available for licensing royalty-free to all seed companies in sub-Saharan Africa. Seed companies have actually started seed production of the new hybrids for introduction and sales in four WEMA countries, namely: South Africa, Uganda, Tanzania and Kenya. For example, on 26 May 2015, the drought gene was approved for commercial release in South Africa. After the successful release of the drought gene in South Africa, the WEMA partners in South Africa started testing the drought gene stacked with the Bt gene, so that eventually they can give farmers the variety with both the drought and the Bt genes. In South Africa, the authorities require that regulated trials are conducted, before application for general release. The regulator release requires data from at least two sites for at least two seasons. During the time of data collection (i.e. August 2017), the WEMA partners in South Africa indicated that they had 3 sites and did more than two seasons, meaning that they fulfilled the requirements of the regulator release. As a results KI1 reported that they had the Dossier ready for submission before the end August (i.e. 2017) to get the stacked genes out for commercial release to farmers.

During the follow-up discussion on the 16th November 2018, it was noted that the application for the approval was rejected. The WEMA partners expressed their disappointment regarding the South African Executive Council for GMO's rejection ruling on the application for general release of the product. The reason given for the rejection was that the data provided in the application were insufficient to demonstrate the efficacy of the drought tolerant and insect resistance.

During the focus group discussion farmers that participated in the WEMA trials expressed their satisfaction regarding the performance of the WEMA products. However, one of the issues related to the deployment of WEMA products from the farmers' point of view was the lack of WEMA products when needed. The farmers indicated that after being impressed with the performance of the WEMA products during the field demonstrations, they made a selection of the varieties to buy for their fields, but to their disappointment there was a shortage of seeds. This experience of the farmers was substantiated by KI1 during the discussion with him in 2017, where he mentioned that the President and CEO of ARC met with senior managers of the private seed companies Capstone and Jermart to discuss the lack of WEMA seeds and that they discussed the best way forward to ensure that the farmers would get their seeds in the next summer season.

Another issue that emerged from the focus group discussion with farmers was more social and related to the farmers' association dynamics. For instance, some of the farmers were not happy with how the finances and financial records were handled. Some of the respondents cautiously indicated that they do not want to criticise fellow association members and leaders. Nevertheless, they indicated their desire for good governance, appropriate record keeping and financial management. For instance, they suggested using an association bank account to keep track of the financials and improve transparency and accountability. Although the respondents indicated that there was a treasurer, there the concern was that financial statements were either unavailable or not shared. The respondents emphasized that record keeping was essential and should be enforced because the farmers did not feel comfortable reprimanding their fellow members. Alternatively, the WEMA partners could train and empower the farmers to be able to enforce good practices among themselves.

During the follow-up discussion with the WEMA partners in November 2018, KI1 revealed that the WEMA project ended with phase two at the end of 2017. The informant reported that when WEMA partners submitted the concept note and the proposal for the phase 3 of WEMA project, then their funders agree to fund them on condition of changing from being phase three to a new project, which concentrates only on the GMO technology instead of both the conventional and GMO technologies. According to the respondent, the funders said there was no point in continuing to emphasise on the conventional seed technology, but to actually put more focus on the GMO technology. Another reason was that, apart from South Africa, over the last 10 years of the WEMA project, no other WEMA partner country commercialized any GMO technologies. It was noted that other WEMA partner countries have made a lots of progress regarding the policies and the regulatory environment, but they were no GMO seeds approved for commercial release. The summary of the progress made by these countries is presented in table 3. Each country has its own barriers and reasons as to why they have not yet given any approval. In Kenya, for instance, there is a ban for the import of GMO foods and that hinders the authorities giving approval to commercial release of GMO varieties. Thus, the respondent noted that although Kenya approved that Bt can now be evaluated in multi-location trials for the purpose of releasing and registering the varieties, the letter of approvals was written but withheld from the WEMA partners to essentially warrant them to actually go and do the trials in the field.

Table 3: Summary of progress in other WEMA partner countries[7]

Conventional hybrids	**GM component of WEMA: Bt (MON810)+DT(MON87460)**	
Overall, there has been adequate progress on conventional hybrids. Many hybrids are registered within WEMA participating countries	Kenya	Environmental release of Bt (MON810) approved by regulators but no implementation due to current ban on imports of GM foods
	Uganda	Regulated trials completed but no regulations to enable commercial release
	Tanzania	Regulated trials started in 2016
	Mozambique	First regulated trial to be harvested August 2017
	Ethiopia	Regulated trials to start 2017
	Malawi and Nigeria	Want to join the WEMA PPP

What factors enable and/or constrain the WEMA arrangement?

Disputed outcomes

Despite the findings of WEMA partners in South Africa, that the drought gene gave at least a 10% increase under drought conditions, soon after the release, the African Centre for Biodiversity (ACB) appealed the release in August 2015. According to KI1 the ACB was questioning the release process since every technology should undergo a process of

7 This table was compiled based on the presentation on WEMA progress given by Dr Kingston Mashingaidze, WEMA regional coordinator, South Africa on the 23rd of August 2017. The follow-up discussion in November 2018 did not suggest changes regarding the progress of the other countries, except to indicate that the Executive Council for GMO from South Africa have rejected the application for the general release of the triple-stacked product.

evaluation by the regulator release authorities. The allegations included that the drought gene did not provide the benefits that were claimed, there was inadequate risk assessment into the adverse effects of the drought gene; there was no comparison with conventional maize under drought conditions, and no information on the impact of Bt on insects. However, KI1 denied the ACB's allegation that there was comparison with conventional seeds under drought conditions by noting that the WEMA partners were actually testing the conventional seeds against the GMO seeds. The respondent indicated that WEMA partners did those trials with a minimum of eight pairs or ten pairs (i.e. one hybrid with the gene and the same hybrid without the gene), depending on the seed availability during the season. Given this contested situation, the minister of agriculture eventually set-up an appeals board to rule on the matter, and they ruled against the allegations of ACB.

During the follow-up discussion in November 2018, it became apparent that the ACB continued disputing the release of WEMA triple stacked products, and that time around the ACB succeeded. Thus, after Monsanto agreed with the WEMA partners that it can make triple stacked products accessible to smallholder farmers wherein the smallholder farmers will pay only the technology fee for the round-up ready while large scale commercial farmers have to pay fees for the three (i.e. Bt, drought gene and round-up ready) technologies, the WEMA partners stopped submitting the *Dossier* for the double stacked product and instead stipulated the application for the triple stacked product. The reason for this is that WEMA partners emphasized that the best products for smallholder farmers in the long term would be a triple stacked because these farmers spend a lot of time and efforts controlling weeds. Furthermore, the WEMA partners believe the best seed technology that supplement drought gene under drought situation would be the technology that enables farmers to have a crop that is weed free. Consequently, the WEMA partners maintained that round-up ready would enlarge better complementary gene than the Bt if they are able to compare the two, to say which one is better.

We then asked WEMA partners what does the outcome of the rejection means beyond just their disappointment. The WEMA partners maintained that decision of the Executive Council for GMO from South Africa to reject the application for the general release of the triple stacked does not make sense.

> *"They are saying we didn't do enough. We didn't generate sufficient data to convince the decision makers that the technology is working, but then it does not make sense. Why, because the Bt gene is already in commercial use on its own as well as in combination with the round-up ready. The drought gene was approved for commercial release in 2015 and the African Centre of Biodiversity appeal to say there is no sufficient data. So if the executive council approved the drought tolerant gene on its*

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own and the appeals board approved the drought gene, the Bt gene is in commercial use on its own and in combination with round-up ready, what other information do they really need from us to say these three technologies are working? It doesn't make sense." (KI1)

Therefore, the WEMA partners indicated that the implication of the final decision taken by the regulator release in South Africa puts to risk the whole WEMA project. They indicated that the outcome is essentially is fundamentally a victory for the ACB as far as South Africa is concerned and that it also puts the difficult position in the minds of everyone else who is in WEMA project in the other countries because all along other partner countries were looking at South Africa to say it is progressive. South Africa was considered progressive since it has already commercialised GM technologies since 1990s and as a result other WEMA partner countries looked up to it in commercialising and deploying GM technologies. Therefore, the concern was that when the other partner countries hear that the same technologies that WEMA partners are trying to get out of the WEMA project, South Africa has now rejected them, this would really just confuse them.

Stakeholder concerns

It is relevant to get buy-in of and/or feedback from other stakeholders (other than WEMA partners) directly and indirectly involved with farmers, concerning new products. Therefore, the WEMA partners in South Africa pro-actively engaged Grain SA (GSA) to gauge how GSA would evaluate the double-stacked product, i.e. the Bt gene plus the drought gene. GSA "provides commodity strategic support and services to South African grain producers to support sustainability."[8] KI1 mentioned that GSA reaction raised three concerns. The first concern was the export implications to countries like Korea. According to the informant, GSA argued that it is important that those who provide and facilitate the technology check with all the potential markets to ensure that the resulting products are acceptable, before any technology is made available to farmers. Accordingly, GSA revealed to WEMA partners that even if WEMA partners get the Bt plus drought resistance approved for production in South Africa, the implication could be that when the maize is mixed (i.e. there is no separation of the crops), this would jeopardise their ability to market their produce to places like South Korea, where the product is not approved.

Another concern was that Monsanto Commercial, had, in February 2017, submitted an application to Department of Agriculture Forestry and Fisheries (DAFF) to get the triple-stacked seeds [BT, drought and herbicide resistance (i.e. round up resistant seeds)] approved for commercial release. According to KI1 WEMA partners negotiated that Monsanto provide the

[8] Available at https://www.grainsa.co.za/pages/about-grain-sa/overview. Accessed on 07-03-2019

WEMA project with drought gene and the Bt gene. Further, it was reported that at the time of the launch of the triple-stacked product Monsanto had undertaken that it will make available at least 3 triple-stacked hybrids for WEMA. The discussion with the company was whether it would give the 'round-up ready' technology royalty-free as well or whether they will charge a developmental fee for 'round-up ready' to the smallholder farmers. Consequently, the WEMA partners in South Africa concluded that farmers could pay for the round-up ready. The argument was that Monsanto cannot just give everything for free, hence the WEMA partners are then saying, let Monsanto give farmers two genes for free, and then they will pay for the third one. Therefore, WEMA partners and Monsanto agreed that WEMA provides the double-stacked as well as the triple-stacked product, and let the farmers decide if they want the product which is 100% royalty-free (the double-stacked), or whether they want the technology which will be a full package (triple-stacked). However, in the latter case, farmers must pay an additional fee.

> *"So as much as the Grain-SA was putting the brake to say we don't want the double stacked products for smallholder farmers, because then you are giving them an inferior product when you are giving large-scale commercial farmers a triple stacked. As WEMA South Africa, we were actually in agreement with them to say let them shoot us down because we also want a triple stacked for our farmers, and that helped us to put pressure on the technology provider." (KI1)*

Shortage of seeds

One of the issues concerning technology transfer components in agriculture that came out during our interactions with the farmers during focus group discussions was that sometimes the demonstrated seeds were not available. Our informants (i.e. KI1 to KI5) corroborated what the farmers said, that lack of seeds was indeed sometimes a challenge within the WEMA project. These informants reported that they used several ways to create awareness and demand by farmers, which include farmers' field days, demos and workshops. They also organise demos and meetings to engage local seed companies by getting them aware of the hybrids and to get them to produce the seeds. Despite these efforts, there was a lack of WEMA seeds in the last summer season (i.e. 2016/2017). In response, our informants again held meetings with the local seed companies to discuss the best way forward. During these meetings the two private companies committed to produce and market certain quantities of seeds. Thus, Capstone company committed 50 tonnes and Jermart seed company committed 80 tonnes. This was surprising, as one would expect that Capstone being a bigger company than Jermart would commit relatively more tonnes. However, this was not the case, because according to KI1 Capstone indicated that they have their own varieties that are already marketed and known to farmers. Jermart is a start-up company and therefore, putting all its efforts on selling WEMA seeds.

"Farmers are interested and ask where they can buy the seeds that were used in the trials? Then we give the details of [company name]. But when the farmers contact [company name], the company indicates that it doesn't have the seeds? So it means we give farmers hope that the next planting season seeds will be available. Then when the time for planting comes, there are no seeds available." (KI4)

"[Company name] is a bigger company, which has been operating for a long time and therefore have their own varieties that are already marketed and known by farmers; whereas [Company name] is a start-up company with no varieties of its own, therefore basing all its efforts on WEMA seed." (KI1)

Needed expertise and skills

The KI3 (private company manager), stated that maize seed production requires a high level of management know-how compared to production of maize for consumption. Looking closely at the different responses from our informants (KI1-KI5) and farmers (FI1-FI5) as well the focus group discussion participants, we can indicatively say that the way of doing business between the smallholder farmers and the private sector is not yet normal in the sense that perhaps the levels of productivity are currently nowhere near the requirement of most private sector players to be interested in dealing with these farmers. This could explain the decision by the private sector company to have resorted to leaving the concerned farmers and to start working with a relatively established farmer, who according to the private company owner needed less technical and monitoring support from the company. However, KI1 indicated that the established farmer also received 100% technical support from the ARC. Based on the discussion with KI3, the informant seems to have expected certain levels of productivity, technical know-how and management capacity from the subcontracted farmers (IF1-IF5), and when his expectations were not met, he became disinterested and could not bear to continue working with them. However, from a public point of view there seems to be a general understanding that smallholder farmers need adequate support and backup before they can achieve a normal way of doing a business.

"If you don't produce good quality seeds, where do you expect to find a market? Because those are hybrids, it is not like OPVs. OPVs were easier to multiply; but with hybrids this is more difficult." (KI4)

"...because seed production requires a high level of expertise, (...) and because I was starting from scratch with farmers who have no experience with seed production, it takes time. With

farmers who are used to seed production, the process is not costly because you just give them the seeds and leave them and they will deliver the quality finished end products. (KI3)

Therefore, in addition to technology offering, provision of sufficient support such as technical back-up to the subcontracted farmers can help in building their resilience and by so doing private companies will also climate-proof their own business interest while unlocking the shared value and opening up to new opportunities. Another aspect to look at the source of the problem regarding this case could be that there was no formal agreement between the subcontracted farmers and the private company concerned. The result of this is that when something goes wrong another party may end-up not being liable. For instance, one of the respondent farmers indicated that at one point he agreed with the private company owner to hire extra labourers for weeding and in the end the company refused to cover all the costs of labour, meaning that the uncovered costs were subtracted from the farmer's profit. These kinds of issues can largely be addressed with a written agreement which includes all specific relevant details.

Reluctance of local seed companies to market the new seeds

One of the major challenges experienced was the disinclination of the local seed companies taking up WEMA products. A possible explanation was that large companies have their own breeding programmes. Therefore, KI1 suggested that WEMA partners should have included as many seed companies as they could. Thus, instead of working with only one large private partner (i.e. Monsanto) a reasonable option would have been to work with other private partners as well.

"What we found to be a big challenge was that the seed companies didn't rush to get our products as much as we thought. Why? Because they have their own breeding programmes and they said, oh well, we also have breeders developing cultivars that are tolerant to all different kinds of biotic and abiotic stresses including drought. What I think we should have done differently is that, when it comes to actual product development, we should include as many seed companies as we can in terms of doing the actual field evaluations before registration sessions. (KI1)

Upkeep of previous relationships

Regarding the deployment of technology from the public side, WEMA partners expected pro-activeness from the provincial departments of agriculture, yet their expectations were not fully met. KI1 noted their dissatisfaction regarding the activities of the provincial department of agriculture towards WEMA product deployment. This was despite their efforts to visits all provinces in 2018 to meet with different food security sections of the departments of agriculture. However, what emerged from the discussions of the WEMA partners and the provincial departments of agriculture was that the departments did not acquire seeds directly from seed suppliers (e.g. research institute or private companies), but they put contractors (through tenders) to provide the seeds and all other technologies. In most cases, these contractors have already established partnerships with different seed companies and they are not always ready to source from other companies to supply WEMA products. While it is acknowledged that the government itself has systems in place and relationships with other partners that cannot just be discarded, it is necessary to use policy space to create a conducive environment to introduce royalty free seeds to farmers.

"Actually, we would have wanted the provincial departments of agriculture to work with us much more closely than they did. In terms of deployment, they were actually our biggest disappointment because if the whole project is meant for smallholder farmers and they are the ones working for them, but it is also a question of

expecting too much on our side. (...) So I can't simply dump that kind of a relationship simply because [...] is bringing drought tolerant WEMA seeds. So is a complex thing. So as [...], I wish that we can get more support from the province, but I guess as much as I say that, am also being unfair by not recognising the fact that the provinces have been getting seeds from their contractors and those contractors have built relationships that they cannot simply change overnight. KI1

Contractual arrangements

Respondents IF1 through IF5 indicated that the WEMA varieties that they planted gave a good yield compared to the traditional seeds that they had planted before. However, they raised issues concerning the contractual arrangements they had with the private company that subcontracted them for seed production. The arrangement was the provision of seeds, fertilizers (in some cases) and technical expertise during planting season and that after the harvest their produce will be graded based on agreed quality and quantity standards, and at the basis of prices determined by the private company and after costs of the inputs (seeds and fertilizers in this case) are deducted, the profit for the farmer can be calculated. The respondent farmers shared their dissatisfaction when it comes to the profit they received and indicated that in some instances the company did not show up to collect the seeds leaving them frustrated and feeling abandoned with an output that is not marketable.

However, KI4 and KI5 from the provincial department of agriculture indicated that one of the main reasons the private company (i.e. of KI3) did not collect the output of the farmers was that the seeds were contaminated. The informants attributed this to inadequate support of the farmers. This was corroborated by another informant, KI1, who indicated that the lack of adequate support came about because the private company in question was a start-up and did not have enough human and financial resources to provide the needed technical support (see also under *needed expertise and skills)*. These were his words.

"He was supposed to go back to tell them that it is a failed crop, rather than to simply abandon them. (...) But for me the major reason was that he didn't have the money to employ a seed production assistant to work with the farmers and to visit them to say if they are doing well and indicate the aspects they have to improve on." (KI1)

5. Discussion

Characterization, performance and development outcomes of the WEMA PPP

Fundamentally, the involvement of institutions and industries to pursue collaboration and combining all available public and private skills and resources determine the beneficial impact of PPPs (Ponnusamy, 2013; Scharle, 2002). Similarly, the WEMA case highlighted elements of success. According to KI1 and KI2 the development of the PPP itself (i.e. the WEMA project) was considered to be a positive outcome and the informants reckoned that improving the PPP can actually be the best way forward in terms of mobilizing financial resources, human resources and also in terms of developing future plans and finding new partners. The development of WEMA was probably considered a positive outcome because in general PPPs are difficult to be maintained. Therefore, developing one and getting it running is already a positive outcome as it suggests you have overcome at least one of the challenges, which is to get a buy-in of the partners. KI1 noted that within WEMA PPP, the partners brought in their different expertise, while the partners were also learning from each other.

In the case of WEMA, the local seed companies had the role of employing farmers to produce the seed varieties, so that they can make money. KI1 noted that getting the public and private organizations to work together within the WEMA project enabled the five WEMA countries to make 22 conventional drought tolerant varieties available to farmers. The WEMA is also valued by other countries. For instance, Ethiopia is now the six WEMA country partner, and Nigeria and Malawi are also willing to join the partnership. KI1 indicated that this growing interest from other countries can only be generated by the success stories of the WEMA PPP. Thus, policymakers in countries like Ethiopia have realized the benefits of this kind of technologies and are, working towards adopting policy environments that allow for public research and testing.[9]

[9] Available at https://croplife.org/transforming-africas-agricultural-programs-with-plant-biotech/. Accessed on 08-03-2019

Furthermore, the fact that WEMA products were made available to farmers' royalty-free signifies that the WEMA partners took into consideration the fact that the majority of smallholder farmers tend to struggle with affordability of new technologies. Also, Ponnusamy (2013b) recommended that those who want to take up a PPP as an empowerment model should pay attention to affordability of new technologies to smallholder farmers. Nonetheless, despite the above mentioned successes, factors were also highlighted that can enable or hinder the WEMA arrangement and eventually the adoption of CSA technologies by smallholder farmers. The following subsection will look at those factors within a broader literature context.

Important factors constraining the arrangement as reflected in previous studies

Shortage of seeds as a technology in question in this study, was considered a factor that can constrain the WEMA arrangement. One of the provision of WEMA partnership was to offer private seed companies with the sub-licenses and basic seed materials so that they can produce and market seed of those WEMA varieties to ensure that the seeds are taken up by smallholder farmers. This was thought to can ease access of the WEMA seed varieties by smallholder farmers since literature noted that seeds business depends on the availability of good supply of high quality basic seed for production of certified seed that can then be distributed to farmers (Spielman *et al.*, 2012). However, our research shows that not only should good quality of basic seed be available, as the capacity to produce and market seeds is equally important to ensure that farmers actually get the seeds on the shelf. In other words, low adoption rates and shortfalls in the supply of improved seed varieties can be partly attributed to bottlenecks emerging from the actual production of seed which then affect the available quantity to be marketed. According to Mabaya (2016) the need for a diverse range of seed companies allows for increased focus on customer (i.e. smallholder farmers in our case). In the case of WEMA, bottlenecks happened because bigger companies with adequate capacities were not enthusiastic to producing WEMA varieties as expected due to various reasons. This saw smaller companies overcommitting and failing to deliver. This is not totally surprising given that South African seed sector though matured, has evolved to primarily serve the needs of large-scale commercial farmers, with the industry often performing poorly on measures that are specific for smallholder farmers (Mabaya, 2016). Therefore, partnerships like WEMA needs to take all these into account when negotiating for private sector involvement so that they can indeed improve access to seed technologies for smallholder farmers in rural areas.

Whilst PPPs in general serves as governance tools that formalise partnerships between stakeholders and involves strong political support (Qizilbash, 2011), maintaining previous relationships is also central to the effectiveness of most government supply chain process. It was evident from our research that the provincial department of agriculture valued their previous relationships with their procurement agents (i.e. contractors) who also had their established relationships with different seed companies they may fall outside WEMA arrangements. In cases like this, some of the WEMA arrangements were not all fulfilled and this was in line with previous research where it was acknowledged that PPP in agriculture suffers due to problems associated with mode of procurement that tends to affect cooperation and coordination between the partners (Ponnusamy, 2013).

6. Conclusion

The WEMA case was found to be a good case to demonstrate how PPPs work in practice by highlighting the benefits of bringing partners together with different capacities. The WEMA case also demonstrated specific country contexts must be taken into account, more especially when the partnership is at the regional level. For example, of the five WEMA partner countries, only South Africa has a mature seed industry, where big seed companies are competing and have their own breeding programmes. The driving force behind these companies is competition and profit. According to informants, that is the reason why some of these companies continue to sell old varieties, even when they have got new varieties in their companies, “simply because they are their cash cows”. Therefore, the inference is that in a mature industry (like in South Africa) where profit matters and multiple companies compete with their own varieties, new varieties will not just easily make it.

However, other WEMA partner countries, like Kenya, Uganda and Tanzania, where a multitude of small-seed companies exist, without own breeding programmes can provide leverage points for projects like WEMA. However, PPPs must consider this alternative with caution, as relying on start-ups and emerging companies comes with a risk since such companies are more likely to lack the human and financial resources to deliver their commitments. Therefore, a strategic balancing act in terms of assistance and support to such companies is necessary.

This study also highlighted that the process of getting the seeds in the hands of farmers is equally a daunting process that do not depends on the views and standards of farmers alone. For instance, other parties working directly/indirectly with farmers or on their behalf can as well stand in the way of a new technology. Also the failure of smallholder farmers to deliver when they receive the seed technologies but inadequate technical support and supervision must be taken into account.

The result of the study highlighted that the process of enhancing technology adoption through PPP is more challenging when other groups or organisations dispute the potential of that particular technology. For instance, in case of WEMA project the objection of the ACB against the potential of drought-tolerant GM hybrids which led to their objection against its authorisation had implications. If indeed the triple stacked product is a superior product and best seed technology that supplement drought gene under drought situation by enabling farmers to have a crop that is weed free, therefore its authorisation for the cultivation would be a significant step forward not only in reducing the impact of climate change and improving food security, but also in reducing the time and efforts farmers spend in controlling weeds. As a result, government through its policies can create an enabling environment that will ensure that access to 'good and beneficial' technologies is not unnecessarily delayed or opposed to serve interest of the minority groups at the expense of majority beneficiaries. This is not to suggests that government policies should undermine the extent to which related policies on biosafety that aimed at safeguarding health, environment and socio-economic wellbeing achieve their objective. Instead the policies need to be based on the objective decision as much as it is possible.

Results also highlighted that despite the existing relationships and government systems in place, policy space can be used to create a conducive environment to introduce royalty free seeds to farmers. For instance, South African policy makers already have various programmes in place such as the programme for food security whereby they provide input support to smallholder farmers to enable them to get access to seeds, fertilizers, etc. As a result, the government is already working with farmers and can use the policy space to renegotiate the terms of engagements with their contractors (who source technologies on their behalf) to ensure that the targeted technologies end up with the farmers, whilst still safeguarding their relationships to the benefit of their targeted beneficiaries.

The provision of support services remains one of the key important interventions in the agricultural sector for rural development, climate change response, food security and poverty alleviation of farmers. Our results emphasized certain expertise and skills are needed in order for the way of doing business between the smallholder farmers and the private sector to be normal. Technical back-up related to the promoted technology to smallholder farmers need to complement the policies which are geared towards smallholder farmers' development. Production of hybrids crops for seeds require that crops be 100% de-tasselled to ensure that the seeds are not contaminated as the contaminated seeds are not marketable. All these technical know-hows are attainable with sufficient technical back-up.

Despite the lessons learnt from this case study, one of the limitations of this study is that first hand discussions were only held with WEMA partners in South Africa. Nevertheless, their insights and experiences were used to reflect on the WEMA partnership at the project as well as at the regional level while zooming in to what actually happened at the country level of South Africa. A follow-up study can zoom in at the regional level by using discussions with respondents from all the partner countries and organisations. Also, it would be beneficial to include all the companies that progressed with WEMA products in other provinces of South Africa to ascertain if they face similar or different challenges.

6

General Discussion, Conclusions, and Implications

CHAPTER 6

6. General Discussion and Conclusions

Considering that the results of each study have been discussed separately in chapters 2 to 5 of this thesis, this chapter goes a step further by integrating the main findings, discussing their theoretical and practical implications and providing directions for future research. Thus, section 6.1 focuses on the main findings and conclusions regarding the main research questions. From an academic point of view, Section 6.2 contributes to the literature related to technology adoption by integrating the perspectives of agri-technology providers and smallholder farmers. On the one hand, from the perspectives of the farmers, this thesis highlighted how farmers' socio-economic factors and their perceptions on CSA technology characteristics influence their adoption decision. On the other hand, from the perspectives of the agri-technology, this thesis emphasized the role of agri-technology providers and provided arguments on why their business models matters for technology adoption. Furthermore, the role of public-private partnerships as one of the ways employed to enhance technology adoption within smallholder farming was explored. In section 6.3, we acknowledge the main limitations of the current research and suggest directions for future research. We outline the implications of the present research outcomes for policy makers and agri-technology business managers in 6.4.

6.1 Main findings and conclusions regarding the research questions

Climate-smart agriculture (CSA) fosters sustainable development of agricultural systems through practices and approaches that are directed to attain improved food security, increased resilience, and low-emissions in the face of a changing climate (FAO, 2010; Sain *et al.*, 2017). However, the main challenge is that while CSA technologies exist, they are not adequately adopted. Insufficient adoption of potential CSA technologies is as a result of several barriers that are experienced by the users and providers of these technologies. Long *et al.* (2016) provided an assessment of the context of CSA technological innovations in European countries by identifying key barriers to adoption of CSATIs in the Netherlands, France, Italy and Switzerland. For instance, technology providers noted that CSATIs were too expensive for the potential customers (Long *et al.*, 2016). Groot *et al.* (2019) highlights the Asian context by introducing the concept of scaling to try and explain the large scale adoption involving multiple actors at various levels to bring about the necessary changes to improve food security in the face of the changing climate. Although studies by Long *et al.* (2016) and Groot *et al.* (2019) concur that numerous CSATIs fail to achieve their full potential impact due to low levels of adoption by smallholder farmers and obstacles in scaling CSA, the issues are not all the same. For instance, Long *et al.* (2016) found that difficulties in proving the added (economic) value of and demonstrating the positive (environmental) impact of CSATIs to customers hinder SMEs in selling their CSA services. On the other hand, Groot *et al.* (2019) found that SMEs selling CSA services have a clear value proposition for their customers. Literature regarding what restricts the adoption of high potential CSA technologies by smallholder farmers and how adoption of these potential CSATIs can be enhanced is not conclusive. Consequently, as has been indicated in the introductory chapter of this thesis (i.e. Chapter 1), the key objective of the thesis was to: *identify and analyse the drivers and barriers for CSA technology adoption, both from the perspective of technology providers and smallholder farmers, and to investigate the effectiveness of specific strategies to enhance CSA technology adoption.*

Driven by the challenges of climate change, a large body of literature is concentrating on CSA technologies and practices that can help enhance farmers' resilience and achieve mitigation where possible while increasing productivity of the farmers (Khatri-Chhetri *et al.*, 2017; Long *et al.*, 2016; Mwongera *et al.*, 2017; Nyasimi *et al.*, 2017; Partey *et al.*, 2018; Senyolo *et al.*, 2018). This dissertation offers new insights regarding the effective diffusion and adoption of CSATIs which can help smallholder farmers to reduce their vulnerability to the effects of climate change. Our research helps to view the barriers to adoption of CSATIs through the lenses of both farmers as the end-users and the agri-technology providers as developers and providers of the technologies. This approach is helpful in establishing demand-driven innovation processes, which is necessary in enhancing technology adoption in a BoP context.

In an effort to contribute to understanding the drivers and barriers to CSA adoption in the North Eastern South African (i.e. Limpopo Province) context, this study applied an interdisciplinary, mixed-method approach, incorporating both qualitative data from semi-structured interviews and focus group discussions, and quantitative data from farmers' surveys. Generally, the study evidences that several barriers to diffusion and adoption of CSATIs exists at the level of both providers and end-users (as Chapters 2 through to 5 and previous studies highlighted). Numerous barriers faced by farmers appeared to be influential to their ability to adopt the CSATIs (Senyolo *et al.*, 2018). A number of those demand-side barriers can be traced back to a limited understanding of the end-user needs by the technology providers who develops and provide the CSATIs (Long *et al.*, 2016; Senyolo *et al.*, 2018). The likelihood of the interaction of supply and demand side barriers suggests the need to tackle both the supply and the demand side in order to overcome barriers to adoption. Therefore, studies which intend to explicitly explore these interrelations are becoming increasingly valuable.

Regardless of the climate-related challenges, it is undeniable that several barriers precede inadequate adoption of high potential CSA technological innovations (CSATIs) at farm level (Biazin *et al.*, 2012; Long *et al.*, 2016). Therefore, understanding the barriers, but also the opportunities, for effective technology adoption is essential, particularly given that smallholder farmers in Africa are especially exposed to climate change and need CSATIs (Grainger-Jones, 2011). Context is crucial when dealing with CSA (Taneja *et al.*, 2014; Zilberman *et al.*, 2012), especially because certain regions require specific CSA interventions (Asfaw *et al.*, 2016). Numerous projects and initiatives whose objectives and activities are consistent with CSA principles in South Africa signified the high level of awareness on matters concerning climate change, and were likely to gain momentum when CSA policies at national, provincial and local levels are put in place (Mnkeni & Mutengwa, 2013). For these reasons, understanding what CSATIs have been introduced and their characteristics not only could highlight barriers and opportunities for effective adoption of CSA technologies and practices. Instead, these projects give us a better idea of the context within which the drivers, barriers and wider question are set.

Moreover, this thesis offers further details to deepen the understanding of the CSA adoption puzzle in South Africa. Next to gaining a contextualised understanding of CSATIs directed at smallholder farmers, their attributes use by farmers, and how the different technologies are introduced to farmers, a better understanding of smallholder decision making about CSA technologies is essential. This knowledge will help to pinpoint how opportunities might be created to assist farmers in implementing CSA.

6.1.1 Specific conclusion with respect to research question 1 (Chapter 2)

The aim of Chapter 2 was to:

> *Identify specific CSA technologies related to water use and management available in South Africa, to describe their characteristics, their context of their application, and their application, and their potential to address climate change.*

Notably, previous research focused on the impact of climate change on South African Agriculture (Gbetibouo & Hassan, 2005; Maponya & Mpandeli, 2012a; Walker & Schulze, 2008), its sensitivity to climate change (Blignaut *et al.*, 2009) and to decreasing water resources (Schulze, 2011). Clear knowledge gaps however, exist in relation to how socio-economic and other factors impact CSATIs adoption and diffusion in South Africa. For these reasons, understanding how socio-economic conditions interact with the characteristics of CSA technologies and practices formed part of this research. Accordingly, it was necessary to conduct the study presented in Chapter of this thesis given that exploration of the characteristics of CSA technologies is the first step to understand their adoption.

Therefore, in chapter two, we identified available CSATIs in South Africa and examined their characteristics and context of use. The chapter primarily served as a context of the research project by indicating the specific climate related challenges that South Africa face, the impact on specific crops, as well as the available and promoted CSA technologies and practices that are potentially able to address these challenges. The predicted impacts of climate change for rain-fed agriculture in South Africa, characterized by poor rainfall, frequent droughts and periodic flooding, particularly within the context of an increasing population, implies that climate change poses considerable challenges (Bogdanski, 2012; Senyolo *et al.*, 2018), requiring the uptake of sustainable technological innovations directed at sustainability goals (Karakaya *et al.*, 2014).

To gather insights in Chapter 2, we undertook two main steps. First, based on literature review, specific climate challenges that South Africa face, the broader CSATIs available to deal with these challenges and the different categories available to characterise CSATIs were established. Based on the review a framework for categorising technological innovations was developed. Second, primary data was collected through semi-structured interviews with several stakeholders including governmental officials, researchers from state-owned research institutions and universities, companies, farmer organisations and NGOs. The interviews provided information on specific CSATIs used within the South African context to mitigate climate risks and the key factors impacting their adoption. Lastly, the framework for categorising CSATIs was then applied to explore the key characteristics of the available CSATIs, and how these characteristics may impact adoption.

Through the exploration of the available CSATIs, this chapter served as an initial assessment towards understanding the context of CSATIs in South Africa. The outcomes indicated that Conservation Agriculture (CA), Rain Water Harvesting (RWH) and Seed Varieties that are Drought Tolerant and Early Maturing (DTSVs) seemed to be the most suitable technologies and practices for the South African context. However, high initial investment costs and additional labour requirements, as well as intensive management attention associated with CA and RWH, might render these technologies less advantageous for smallholder farmers. DTSVs, especially the Open Pollinated Varieties (OPVs) were noted to be less costly, not management intensive, and therefore could present better prospects of adoption by smallholder farmers. Previous research noted lack of skills in the application of the CSATIs to be an issue (Groot *et al.*, 2019; Montalvo, 2008) as well as the price of the of the CSATIs (Long *et al.*, 2016). The fact that high initial investment costs, additional labour requirements and management intensiveness may render some CSATIs disadvantageous, conform with the existing literature that noted price and lack of skills to be an issue. These results suggest that technology selection is not purely depend on contextual factors. Thus, other socio-economic such as costs and skills play a role in decisions regarding technology adoption.

Results in Chapter 2 showed that failure to involve the end users (farmers) of technology during the development phase and lack of awareness, knowledge and skills will lead to non-adoption of CSA technologies. These results suggest effective transfer of information concerning CSA technologies, provision of support and complementary programmes and greater involvement of farmers early in the innovation process, are essential in enhancing CSATIs adoption. The need to transfer information effectively could be seen to be consistent with issues related to overly complex language noted by Long *et al.* (2016) and lack of appreciation of day-to-day farm realities noted by Eidt *et al.* (2012). Moreover, engaging smallholder farmers earlier in the innovation process to prioritise and support CSATIs that are more aligned to their agro-ecologies and farming practices may well be a conceivable alternative. Our results suggest that an educational campaign to enhance the level of information regarding CSA technologies and involving the farmers from the outset has the potential to enhance adoption of these technologies. This is because all the available CSATIs identified in our study as having been promoted in South Africa, were found to be semi-continuous innovations, necessitating that information channels to smallholder farmers be increased and that flaws in the way that such information is transferred to them should be circumvented.

6.1.2 Specific conclusion with respect to research question 2 (Chapter 3)

Although Chapter 2 revealed that several CSATIs to address the climate related challenges were introduced to farmers in South Africa, it was also established that adoption of the introduced CSATIs within smallholder communities was not straightforward. Thus getting CSATIs into the hands of the farmers who need them remains a challenge (Nyasimi *et al.*, 2017; Senyolo *et al.*, 2018; Weisenfeld & Wetterberg, 2015). Therefore, the aim of *Chapter 3* was to*:*

> *better understand smallholder decision making about drought- tolerant seed varieties as an example of a CSA technology, in order to pinpoint how opportunities might be created to assist farmers in implementing CSA.*

Technology adoption in general and transition to CSA in particular, is shaped by numerous factors (Baiyegunhi, 2015; Fischer *et al.*, 2015; Long *et al.*, 2016; Mushunje *et al.*, 2011; Senyolo *et al.*, 2018). These include barriers which often require certain interventions to encourage technology adoption. Despite the initial research, limitations remain evident in the adoption literature investigating the effective adoption and use of CSA technologies within smallholder farmers. First, while perceptions and attitudes of farmers are highlighted as important in previous research (Fischer *et al.*, 2015; Mekoya *et al.*, 2008; Mushunje *et al.*, 2011; Nyasimi *et al.*, 2017; Ubisi *et al.*, 2017; Zubair & Garforth, 2006), they are not adequately addressed and understood (Meijer *et al.*, 2015). Second, considering that farmers' socio-economic conditions and perceptions of technology affect adoption decisions (Bryan *et al.*, 2009; Deressa *et al.*, 2009; Drechsel *et al.*, 2005; Tessema *et al.*, 2013; Ubisi *et al.*, 2017), analysis of the role of these factors within the context of CSA technologies in smallholder settings is important. To date, exploration of socio-economic and socio-technical factors influencing the adoption of CSA technologies in particular is inconclusive. To deal with these limitations, Chapter 3 investigated the factors determining adoption of CSA technologies by exploring not only the farmers' characteristics and contextual factors, but also considered additional factors extracted from farmers' perceptions of CSA technology-specific attributes.

Accordingly, Chapter 3 focused on drought-tolerant seed varieties (DTSVs) for maize as a CSA technology relevant for smallholder farmers in rain fed crop production (Asayehegn *et al.*, 2017; Senyolo *et al.*, 2018). The importance of maize for food security and economic well-being in sub-Saharan Africa in general and in South Africa in particular, makes it a critical crop to investigate. Furthermore, smallholder farmers' maize production largely relies on rainfall, which is increasingly erratic (Fischer *et al.*, 2015). Consequently, unreliable rainfall accompanied by frequent droughts, make it difficult for smallholder farmers to obtain high crop yields and therefore, they are susceptible to food insecurity (Mdungela *et al.*, 2017; Mpandeli *et al.*, 2015).

Three districts of Limpopo Province in South Africa, were DTSVs were introduced and/or promoted, were selected as the area of study. On the basis of probability proportionate to size as well as farmers' willingness to participate in the research, a sample of 196 farmers was randomly selected and interviews using structured questionnaires were conducted. The farmers survey was preceded by the focus group discussions (FGDs) to gain insights in the farming activities as well as the key issues affecting them. First, the socio-economic characteristics data were analysed using descriptive statistics. Second, factor analysis reduced 19 identified CSA technologies specific attributes to 5 factors that were used with other socio-economic factors in a multinomial logistic regression model, in order to test the significance of those factors that influence adoption of CSA technologies by farmers.

Our findings showed that smallholder farmers in the study were using three seed varieties "Hybrids and OPVs (i.e. DTSVs) and Traditional seeds" and in most cases used more than one seed variety in one season and in one field. The results showed a range of drivers and barriers influencing DTSVs' adoption, regardless of the acknowledged potential of the CSA technology. For instance, the variables "Training and demonstration related to DTSVs", "Knowledge possession and benefits related to DTSVs" and "Enabling factors" were found to be significant predictors, suggesting that adequate opportunities for training and extension support, training, demonstrations of technologies, together with supporting elements such as information and additional training regarding the DTSVs had an influence on whether farmers used "Hybrids and Hybrids with either Open Pollinated Varieties (OPVs) or Traditional seeds" or "OPVs and OPVs with Traditional seeds". Additionally, the following variables: "necessary requirements", gender, marital status and credit access were significant in distinguishing farmers who used "Hybrids and Hybrids with either OPVs or Traditional seeds" with Traditional seeds". Corroborating (Kielbasa, 2016; Matata *et al.*, 2010; Mulaudzi & Oyekale, 2015), it was shown that with provision of adequate opportunities for training, access to agricultural advisory services, weather forecasts and demonstrations related to DTSVs, farmers are 2.2 and 2.1 times more likely to use "Hybrids and Hybrids with OPVs or Traditional seeds" and "OPVs and OPVs with Traditional seeds", respectively relative to "Traditional seeds".

When comparing to the adoption literature, two conclusions can be derived. First, it turns out that most of the significant factors found in this chapter concurred with the reviewed adoption studies related to agriculture and climate change. The variable "necessary requirements" was only a significant predictor in distinguishing farmers using "Hybrids and Hybrids with OPVs or Traditional seeds". Thus, although farmers in the study area recognised that it is imperative to be informed about weather information in their area, know about better planting dates for DTSVs and to receive tractors services (and also seeds on time), this was not often the case. Farmers noted their frustration over continuous delay in input and service delivery, which negatively affect their planning in general and planting time in particular. Although alternative efforts to address this included sourcing of the OPVs locally and which may reduce their transaction costs, farmers' opinion regarding some farmers as the local suppliers varied. Some farmers noted that some of their fellow farmers cannot always be trusted as local suppliers to produce and market quality seeds. Nevertheless, local suppliers if appropriately organized, may assist in addressing higher costs in seed procurement and transportation which according to Diale (2011) appeared to be an impediment to adoption of the technology. Therefore, although it is undeniable that local provision of seeds has the potential to reduce the transaction costs of procuring DTSVs, as noted by Diale (2011), the concern raised by farmers over issues of trust regarding production and marketing of quality seeds at local level should not be overlooked.

Second, while credit access was found to be a significant positive predictor of whether farmers were using “Hybrids and Hybrids with either Open Pollinated Varieties (OPVs) or Traditional seeds” to “Traditional seeds”, it was interesting to note that during discussions with the farmers, farmers are more vocal about access to credit than they are about seeds provision by the government. One would expect that in smallholder settings where lack of finance for inputs is usually a challenge, as was the case in this study, government provision of seeds would have been somehow talked about more by the farmers to in influencing farmers’ use of DTSVs. One possible explanation for this remarkable outcome could be that farmers undertake the responsibility either to save or to source their seeds for production, and rather prefer the government to provide other complementary inputs or technologies, such as tractors and manures. Another reason might be that farmers prefer to be provided with credit or finance to purchase seeds in time to avoid late planting as it sometimes happens when the government is providing seeds through its seed provision programmes.

6.1.3 Specific conclusion with respect to research question 3 (Chapter 4)

Departing from the premise that adoption and diffusion of CSATIs is impacted by both supply and demand factors, the focus of Chapter 3 was to understand the demand-side barriers through farmers’ perspectives since they are the end-users of CSATIs. In contrast, Chapter 4 focused on understanding the supply-side barriers from the perspectives of the agri-technology with the aim to:

> *explore the factors that affect the ability of CSA technology providers to diffuse CSATIs to smallholder farmers at the base-of-the-pyramid (BoP), by examining their business models.*

Previous research indicates that several demand-side barriers can be traced back to a limited understanding of user needs by those who design and provide innovations (Long *et al.*, 2016). Supply and demand side barriers are likely to interact, and therefore overcoming barriers to adoption of CSATIs must involve dealing with both the supply and demand side (Long *et al.*, 2016; Montalvo, 2008). Yet, few studies explore the interrelations between supply and demand side barriers (Blok *et al.*, 2015; Long *et al.*, 2017). This chapter used a business model approach to facilitate such an exploration. The business model construct connects supply and demand sides, because it explores and explains the core logic of a business and allows a reflection on how to capture value from providing new products and services that add value for the customer (Bocken *et al.*, 2014; Teece, 2010). Accordingly, business model innovation can improve technology diffusion by reconceptualising the purpose of the firm and the value creating logic, and rethinking the perceptions of value (Bocken *et al.*, 2014). Therefore, in this chapter we used the business model as an analytical lens to explore the interaction between demand and supply by reflecting on the value propositions of agri-technology providers for their customers (i.e. farmers), and the value captured by their products and services (i.e. CSATIs).

To achieve the aim for Chapter 4, face-to-face semi-structured interviews among 10 agri-technology providers served as research material. Building upon the works of Boons and Ludeke-Freund (2013) and Long *et al.* (2017), the interviews data was then studied through the Business Model for CSA Technological Innovations (BM*f*CSATIs) critical issue framework and compared to the critical issues highlighted in the literature. Through analysis consistent with an in-depth qualitative approach which included production of interview transcripts, coding in an iterative process, Chapter 4 provided the key factors of the business models of agri-technology providers and illustrated these with examples from the data. The data provided a supply perspective on the current BMfCSATIs, and highlighted the possible shortcomings of the business model of agri-technology providers.

Our results revealed that existing business models of the agri-technology providers do not seem to be functioning optimally to diffuse CSATIs in targeting smallholder farmers. Hybrid varieties and especially seed maize production requires specific investments in human capital and inputs. This suggests that the value proposition of the agri-technology providers would need to cater both the inputs and human capital in order to be attractive for smallholder farmers. Other scholars noted that difficulties in proving the value and demonstrating positive impact of CSA technologies hinder SMEs in selling CSA services (Long *et al.*, 2016; Westermann *et al.*, 2015), hence provision of inputs and human capital are other ways to prove value and demonstrate positive impact to smallholder farmers. Our results showed that agri-technology providers address smallholder farmers' problems, such as lack of access to input markets, lack of access to storage and grinding technologies and lack of output markets, only to a certain extent. While access and provision of different CSA technologies such as DTSVs motivate the farmers to adopt the seeds, inadequate technical know-how, lack of storage facilities, risk of underpayment in case of fixed-contracts, as well as the lack of freedom to make independent decisions regarding the sale of their produce tend to inhibit adoption by smallholder farmers. This shows the significance of product-service system strategies (e.g., offering services such as soil analysis, maintenance plans, structured training and mentorship) and contracts in order to address smallholder problems and thus for agri-technology providers to improve the adoption of CSATIs by smallholder farmers.

While our empirical findings were largely consistent with key factors identified within the literature, two distinctive viewpoints related to BoP contexts were identified. First, previous research showed that relevant and clearly articulated value propositions would help to overcome the sales and marketing difficulties of CSATIs (Lin *et al.*, 2013; Long *et al.*, 2017). However, our results revealed that for smallholder farmers within a BoP context, an effective value proposition alone is not sufficient to enhance adoption. Second, our findings indicated that the core requirement of smallholder farmers within the BoP goes beyond proof of impact (as it is the case in western contexts), and includes a need for production credit. Given these findings, product-service system could be a business model innovation that would help to overcome barriers to CSATIs adoption in South Africa. We also found that the indirect relationships between the agri-technology providers and farmers lead to higher costs, due to high mark-ups that accompany the use of the sophisticated official procurement systems. Moreover, forging and sustaining key relationships and networks was considered critical to pursue a service-based approach aspired by the agri-technology providers. These partnerships and networks are needed to enhance agri-technology providers' capabilities and resource base to create and capture value.

6.1.4 Specific conclusion with respect to research question 4 (Chapter 5)

The aim of Chapter 5 was to:

> *investigate the efficacy of intervention designed to increase technology adoption by exploring and highlighting challenges identified within the Water Efficient Maize for Africa (WEMA) project in South Africa.*

In Chapters 2, 3 and 4 of this thesis, we established which CSATIs with potential to reduce climate change impacts were introduced and promoted to farmers in South Africa, identified the drivers and barriers to adoption and diffusion of CSATIs from a smallholder farmers' perspective and an agri-technology providers' perspective. It was found that CSATIs individually or in combination have considerable potential to reduce the impact of climate change on agriculture (Bedmar Villanueva *et al.*, 2016; Khatri-Chhetri *et al.*, 2017; Senyolo *et al.*, 2018). Yet, due to several barriers experienced by the agri-technology providers and smallholder farmers alike, the diffusion and adoption of these promising CSATIs remain disturbingly low.

To help overcome some of the barriers hindering the effective and adequate diffusion and adoption of CSATIs, numerous initiatives and interventions have been implemented at various levels. For example, multilateral agencies and agricultural research organisations have implemented different types of pilot programmes to demonstrate the benefits of CSA by highlighting how CSA can deliver the 'triple win' outcomes (Cavanagh *et al.*, 2017). Similarly, government and the private sector have joined forces to intervene with the aim to enhance adoption and diffusion of CSA technologies within smallholder agricultural communities. These joined forces are often in the form of a public-private partnership (PPP), one of the well experimented strategies to realise specified goals within agriculture, education, science and technology, health, infrastructure development and extension (Ponnusamy, 2013). In order to investigate the efficacy of interventions designed to increase technology adoption we studied the PPP, Water Efficient Maize for Africa (WEMA), a PPP with the objective to improve food security and rural livelihoods among smallholder maize producers in sub-Saharan Africa by developing and disseminating the seed technologies which are drought-tolerant and insect-pest-protected (Edge *et al.*, 2018). The WEMA initiative was considered a logical case for this study for the following reasons: at the time of data collection, the WEMA project had been around for more than 8 years, the WEMA project was involved in development of germplasm, as well as testing it, and disseminating the varieties that were developed to smallholder farmers.

The WEMA case enabled us to demonstrate how PPPs work in practice by highlighting some of the successes attained and the challenges that prevailed, as well as the implications for theory and practice. The case study showed that the development of the PPP itself was considered positive by the respondents. They also reckoned that improving the PPP could be the best way to mobilize capacities in terms of financial and human resources helping to overcome some of the barriers hindering the effective diffusion and adoption of CSATIs. The WEMA case showed the need for collaboration between the public (government) and private sector (agri-technology providers) in implementing product-service offerings that have prospect of enhancing the adoption of CSATIs, as smallholder farmers need a package of CSATIs and it appears that agri-technology providers, although willing to partake in the services, are not yet ready to bear all the costs.

The beneficial impact of PPPs depends on the involvement of institutions and industries in seeking collaboration and combining all available public and private skills and resources. The extent of involvement, however, depends on the capacities of the partners within a PPP, ensuring that the partners have enough resources (human and financial) to fulfil their commitments, and not just their aspiration to be involved. Our study revealed that although small seed companies may be more enthusiastic to take up new technologies, they do not always have sufficient resources to accomplish their obligations. Nonetheless, when promoting seed technologies in countries like South Africa with a matured seed industry, where profit matters and multiple companies with own varieties exist, new varieties will not just easily make it. Therefore, in cases where companies with various capacities are involved in a PPP, a necessary condition would be a strategic balancing act to analyse and if possible support the companies that need it with adequate technical expertise and supervision.

Moreover, sufficient smallholder farmers' management capacities are essential to ensure successful adoption of technology. This finding shows that availability of technologies as such is not enough, adequate technical expertise and supervision is needed to complement the farmers' management capacities according to their needs. Failure to address farmers' management capacities can be detrimental, as they may still fail regardless of access to improved seed and other technologies. The issue of technical expertise resonates with previous research which identified lack of skills in the application of CSA technologies as a critical issue for adoption and scaling up (del Río González, 2005; Groot *et al.*, 2019; Montalvo, 2008).

6.2 Academic contributions

This thesis has contributed to the literature on technology adoption, business models and public-private partnerships. This section provides a synthesis of the academic contributions of our findings presented in the Chapters 2 through 5.

This thesis has contributed to the literature on technology adoption by focusing on the agri-technology providers as commercial actors who are trying to sell CSA technologies and smallholders who are expected to adopt these technologies in order to improve their livelihood and reduce climate impact. Generations of researchers and practitioners have sought ways to increase the productivity of smallholder farmers, given their resource constraints. A number of CSA technologies have been developed and tested in research stations that found limited adoption in farming communities (Drechsel *et al.*, 2005; Sullivan *et al.*, 2013). This thesis showed that a range of drivers and barriers influence smallholder farmers' adoption of DTSVs, regardless of the acknowledged potential of such CSA technologies. This thesis addresses one of the key issues in adoption literature: the influence of socio-economic factors and the subjective perceptions of smallholder farmers of CSA technology characteristics on their adoption decisions.

Within the debates on the adoption of new agricultural technology in general and CSA technologies in particular, the outcomes of Chapter 2 corroborate previous research [(e.g. (Diale, 2011; Ikheloa *et al.*, 2013)], that if farmers believe that DTSVs were responsible for high yield and enhanced food security, they are most likely to adopt them to improve their livelihood. However, the likelihood to adopt the CSA technologies in general and DTSVs in particular, is unlikely to be higher when farmers are faced with barriers, such as unaffordability because of lack of access to credit. Therefore credit access and the ability to raise sufficient funds to invest in CSA technologies positively sway the use of CSA technologies such as DTSVs [see (Ikheloa *et al.*, 2013; Oluwatayo & Ojo, 2016)]. While it is undeniable that local provision of seeds has the potential to reduce the transaction costs of procuring DTSVs (Diale, 2011), the element of trust should not be underestimated, as the negative view of some of the farmers in our study area regarding their fellow farmers as local seed suppliers showed.

Chapter 2 suggests that smallholder farmers in rural areas are heterogeneous, with some having better capabilities to adopt different CSA technologies. Therefore, how various stakeholders engage farmers through education, training, demonstration and any form of assistance related to CSA technologies should be tailored to suit farmers' different needs and capabilities.

The thesis has paid due attention to the maize crop, which is the critical crop owing to its importance to food security and economic wellbeing in sub-Saharan Africa in general and in South Africa in particular. Although maize has received some attention related to the threats of a changing climate, the focus of previous research was basically on the effect of climate change on grain yield of maize and economic impact of climate change on the field crops (Abraha & Savage, 2006; Benhin, 2008; Gbetibouo & Hassan, 2005).

This thesis has provided further arguments on how business models of agri-technology providers may influence the adoption and diffusion of CSA technological innovations in base-of pyramid (BoP) contexts. Although several demand-side barriers (barriers faced by smallholder farmers in this case) can be traced back to an inadequate understanding of farmers needs by those who design and provide innovations, few studies explicitly explore the interrelations between both supply and demand side barriers (Blok *et al.*, 2015; Long *et al.*, 2016; Long *et al.*, 2017).

The thesis has provided further insights into the key issues for BM*f*CSATIs, by identifying barriers and enabling factors that can enhance the adoption and diffusion of CSATIs, by smallholder farmers at the BoP. Indeed, the business model literature has recognized the problem of a non-thriving of 'good' technologies due to inappropriate business models that accompanied them (Chesbrough, 2010; Teece, 2010). However, such analysis concerning non-thriving 'good' technologies, especially in agriculture, have been conducted from the perspective of end-users (i.e. farmers), as farmers are the ones assumed to be mostly affected as a result of loss of benefits associated with the new technologies. This thesis complements the findings of Long *et al.* (2017) by showing that non-optimal business models also can serve as a barrier to CSATIs adoption, and further provide the southern context by showing that with smallholder farmers within a BoP context, effective value propositions alone are not sufficient to enhance adoption.

In addition, this thesis has contributed to the agricultural technology diffusion literature by investigating the factors that affect the ability of CSA technology providers to diffuse CSATIs to smallholder farmers at the base-of-the-pyramid (BoP). Due to the unique characteristics and complex circumstances of smallholder farmers at the BoP, serving them is not a straight forward exercise, because besides the fact that they need CSA technologies to address climate related challenges, they often face problems such as lack of access to input and output markets, lack of access to storage, lack of access to production capital and credit, lack of grinding technologies and lack of technical know-how which hinder their adoption of potential technologies.

Although our findings cannot be and are not intended to be generalized, it is believed that they do not only apply to the specific agri-technology businesses studied. Despite their contextual specificities, the key issues that affect the ability of business models used by agri-technology providers to diffuse CSATIs in the context of smallholder farmers were consistent with key factors identified within literature, with the exception of two identified issues peculiar to the BoP. The ability to apply the critical issues for the BM*f*CSATIs framework based on the literature (Gabriel & Kirkwood, 2016; Long *et al.*, 2017; Magretta, 2002; Osterwalder & Pigneur, 2010) in the context of this study already proves its generic character.

Further to the broader literature on business models and their associations with sustainable innovations, most of the key factors identified in the context of our study were not unique either. For instance, our findings noted the need for lower prices that can be affordable to smallholder farmers, and previous research in Europe indicated that lower initial margins may facilitate competition with reputable companies (Chesbrough, 2010; Long *et al.*, 2017). Furthermore, our results noted the need to forge and sustain key partnerships and networks necessary to enhance agri-technology providers' capabilities and resource base to create and capture value (Ceschin, 2013; Voelpel *et al.*, 2004; Wirtz *et al.*, 2016). Our study also revealed that smallholder farmers need a package of CSATIs and that agri-technology providers, though willing to partake in the services, are not yet ready to bear all the costs. These factors which are consistent with western context, together with the additional issues peculiar to BoP contexts make the findings of this thesis relevant on a much broader scale.

This thesis has contributed to the discussion on the role of public-private partnerships (PPPs) as one of the approaches to enhance adoption and diffusion of CSATIs. By analysing the drivers and barriers to adoption and diffusion of potential CSATIs from a smallholder farmers' perspective and an agri-technology providers' perspective, and by using a case study approach, this thesis showed that the development of PPP itself is considered to be a positive outcome. Furthermore, the respondents reckoned that improving the PPP can actually be the best way forward in terms of mobilizing capacities, although there are a number of challenges to overcome. These findings corroborate previous research that suggests that while product-service system innovation is a promising business model, it brings along noteworthy challenges for companies, customers and regulatory environments (Ceschin, 2013).

6.3 Limitations and directions for future research

As research always generates new questions, this thesis is no exception, and has provided several directions for further research. This thesis explored the context of CSA technological innovations (CSATIs) in South Africa, their characteristics as well as factors likely to influence their adoption from the perspectives of farmers (as the usual end-users) and agri-technology providers. This thesis forms a good basis upon which to inform the nature and scope of further investigations. Our results showed the importance of awareness of and access to information by farmers and how information is transferred in advancing CSATIs adoption. So, further research could explore the effectiveness of different information dissemination channels used by government-funded programmes and/or private company interventions to transfer information on CSA technologies to farmers. Some respondents in our study noted that Agroforestry should be among the prioritised CSATIs, yet literature shows that technologies like Agroforestry involve radical change (Loevinsohn *et al.*, 2012). This could mean they are less likely to be adopted as compared to incremental technologies like new seed varieties. Therefore, future research could explore the conditions under which radical technological innovations would be most appropriate and what forms of support may be needed. It is also likely that combinations of technologies may be needed to achieve better results with CSA efforts, so future research could also investigate how this occurs in practice.

From the supply side of technology adoption, this thesis discussed the key issues for business models for CSATIs and the potential role of agri-technology providers in enhancing diffusion of CSATIs, and further discussed the needed adjustments or innovations of the identified business models in order to boost diffusion and adoption of CSATIs. With regard to the interpretation, it needs to be acknowledged that the findings concerning the supply side were based on empirical work carried out among a small study population of 10 agri-technology providers. Further research could investigate its applicability in a larger research setting.

Given the barriers faced by farmers and agri-technology providers alike, interventions are often needed to enhance adoption. In order to investigate the efficacy of interventions designed to enhance technology adoption such as PPPs, Chapter 5 of this thesis used a single case study. Therefore, this thesis, suffered the inherent limitation of a single case study. However, we reinforced the outcomes of our case study through the analysis of patterns and triangulation of data using different sources of information for the same data within our case (as suggested by (Mariotto *et al.*, 2014; Yin, 2009). The WEMA case enabled us to demonstrate how PPPs work in practice as it provides intriguing insights into the relative dynamics of adoption and diffusion of agricultural technology where multiple actors are involved. However, further research consisting of more cases is needed to enhance our knowledge of technology adoption through PPPs.

The outcome of our case study analysis indicatively suggests that the way of doing business between the smallholder farmers and the private sector is not yet normal in the sense that perhaps the levels of productivity are currently nowhere near the requirement of most private sector players to be interested in dealing with smallholder farmers. Future research can explore what specific capacities are necessary for what type of farmers to make them real partners for technology providers.

6.4 Practical implications

This thesis provides several practical implications, primarily to policy makers and to the managers of agri-technology providers as they highlight the key factors that impact farmers' adoption decisions.

The findings of our thesis can be used by policy makers aiming to enhance adoption of CSATIs. Within the policy context, there is an interest in getting more insight into factors enabling and hindering farmers to adopt CSA technologies for increasing productivity whilst reducing climate change impact. In Chapter 2, we observed that training and demonstration were significant in impacting adoption of DTSVs as an example of CSATIs relative to traditional seeds. In this case, policymakers on their own or in partnership with other stakeholders, can mobilize resources and coordinate efforts to provide training and demonstration to farmers regarding the DTSVs. Our findings also highlight that smallholder farmers are heterogeneous, with some having better capabilities to adopt CSA technologies. Therefore, government support of education, training and assistance related to CSA technologies should be tailored to suit farmers' different needs and capabilities.

In Chapter 4, we observed that a large share of the financial resources from government aimed to enhance smallholder farmers' adoption of CSATIs, benefit other chain actors (e.g. tender-preneurs). Respondents reckoned that the government's popular approach of procuring goods and services through tender systems exacerbates the challenges regarding the adoption of CSATIs. Tender-preneuring as a procurement method is susceptible to corruption, due to the exorbitant mark-ups charged by the tender-preneurs to government, thereby inflating government costs of interventions. Therefore, policy makers can choose to shun away from this tender-preneur approach in procurement of CSATIs or reconsider the procurement system by including intensified monitoring and evaluation to prevent the kind of irregularities noted by our respondents. Thus, to enhance CSATIs adoption by smallholder farmers, optimal business models of agri-technology providers need to be backed by high level monitoring of supply chain activities to avoid exploitations.

Furthermore, in Chapter 4, the agri-technology providers observed that product-service systems have a better prospect to enhance adoption of CSATIs. This is because to implement CSA adequately, smallholder farmers need a package of CSATIs and it appears that agri-technology providers, although willing to partake in the services, are not yet ready to bear all the costs. Therefore, in this instance, government intervention in a multi-actor based business model could be the driver that can enable farmers to buy and/or pay for CSATIs.

This thesis has provided important practical implications for managers of agri-technology businesses. The practical relevance of this study was to provide an input for future agri-technology providers concentrating on the smallholder farmers' market or those intending to expand their market to smallholder farmers, particularly with regard to CSATIs. The findings of this thesis show that the non-optimal BM*f*CSATIs serve as a barrier to the uptake of CSATIs by smallholder farmers at the BoP. The identified shortcomings of the business models of agri-technology providers can be addressed through business model innovations.

First, it was revealed that with smallholder farmers within BoP, effective value propositions alone are not sufficient to enhance adoption. It was also noted that in most cases the problem is affordability rather than lack of understanding of the benefits of the CSATIs by the end-users (farmers). Second, the relationships with the targeted customers (i.e. smallholder farmers in this case) was considered vital (Gabriel & Kirkwood, 2016; Ver Loren van Themaat *et al.*, 2013). Some agri-technology providers in our study reported a direct relationship with their customers whereas others reported indirect relationships. The latter scenario often meant higher costs, due to the high mark-ups that government contractors (i.e. tender-preneurs) charge for their services, due to the use of more sophisticated and official procurement systems. Third, financial resources are needed to train and equip targeted customers with modern farm management and technical skills. Fourth, failure to forge or sustain key partnerships and networks needed to enhance agri-technology providers' capabilities and resource base to create and capture value was considered a critical to pursue service-based approach aspired by the agri-technology providers (Ceschin, 2013; Voelpel *et al.*, 2004; Wirtz *et al.*, 2016). Fifth and last, it was stated that low margins are especially needed in order to cater for smallholder farmers.

Thus, the study revealed that there is potential to offer valuable opportunities for agri-technology providers to smallholder farmers, provided the unique characteristics of the farmers are accommodated. Therefore, if agri-technology providers are able to advance to full product-service systems and expand to accommodate smallholder farmers through integrated services, these could help to overcome some of the aforementioned business model shortcomings. For instance, agri-technology providers can explore how they can make money while their products remain affordable to smallholder farmers. This is because price systems are critical since customers are inclined to buy only if the price is affordable (Teece, 2010). Furthermore, the resources and support services needed by the smallholder farmers vary according to the socio-economic circumstances and their type of enterprise, and therefore it is important to provide specific types of support (Gray *et al.*, 2014), in order to eliminate and reduce the barriers that smallholder face in adopting the CSATIs.

Chapter 6

7

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Appendices

APPENDIX 1:

APPENDIX 1: Outline of Respondents in Chapter 2

Table 1.1: CSA stakeholder data source/respondents and their expertise/professions

No	Field of study	Responsibilities within the institution or organisation	Institution or Organisation
R1	Soil Science and Agronomy	Research scientist and farmers advisor	RI
R2	Agricultural Economics	Manager of a company which produces and sell certified seeds	PC
R3	Sustainable Agriculture	Manager and Facilitator of CA program	FA
R4	Engineering	Manager in the Section of Natural Resource Management	GO
R5	Natural Resource Management and Extension	Coordinating CA, Agroforestry and Soil Fertility Management and Land Care	GO
R6	Accounting and Finance Management	President of the association. Interact with farmers and serve as contact person and representative of farmers when it comes to interaction with other agricultural stakeholders	FA
R7	Agro-ecology	Conduct and lead research related to Global Change. Climate Change is one aspect of Global Change	U
R8	Meteorology and Agro-Meteorology	Conduct research on climate change and variability and facilitate transfer of some mitigation and adaptation technologies to farmers	RI
R9	Sustainable Agriculture (Crop & Livestock)	Manager for research section. Oversee and facilitates all research activities	GO
R10	Geography (GIS and Remote Sensing)	Coordinate and manage research related to climate change across all water linked ecosystems	RI
R11	Climate Change, Agricultural and Irrigation Management	Manage agricultural water management projects	RI
R12	Soil Science	Researcher (80% of time spent in the field)	RI
R13	Environmental Management	Responsible for implementation of CA through training	RI
R14	Agro-Meteorology	Manages the unit of climate change and disaster management which coordinates climate change activities, agriculture, forestry and fisheries	GO
R15	Horticulture	Agricultural advisor to farmers in the division which focuses on development, particularly of farmers	PC
R16	Plant Breeding	Managing scientific research within research section	GO
R17	Plant Breeding	Plant breeder. Lecture plant breeding, supervise post graduate students and conduct research related to plant breeding and food security	U
R18	Soil Chemistry and Biology	Conduct research on Biochar which is part of mitigation research	U
R19		Project officers responsible for pre and post-settlements as far as redistribution programme (one pillar of Land Reform) is concerned.	NGO
R20	Soil Science	Conduct research on Precision Agriculture and Socio-economic Development. Conduct and assess farmer needs and challenges	GO

R21	Soil Science	Advise farmers on irrigation management and conduct research on No tillage for maize crop	GO
R22	Agricultural Disaster Management	Coordinator in the unit called Disaster and vulnerability management. Check all the hazards that affect agricultural production	GO
R23	Agronomy	Work under Home Grown (Food brand) and is responsible for primary agriculture where they provide access to inputs to farmers through off-take agreements	PC
R24	Agronomy and Farm and Business Management	Relate and work with farmers. Teach them how to grow maize because it is the company's main resource they need.	PC
R25	Sustainable Agriculture and Ecological Remediation and Sustainable Use	Director in the directorate of land use and soil management. Responsible for land care.	GO
R26	Agricultural Engineering	Researcher within the agricultural mechanization and irrigation section	RI
R27	Agriculture: Agronomy	Lecturing, supervision of students projects. Conduct research on indigenous vegetables, different varieties of maize cultivars (e.g. WEMA)	U

RI=Research Institution, GO= Governmental Organisation/Department, FA= Farmers Association. U= University, PC= Private Companies providing and selling technologies, NGO=Non-Governmental Organisation

Appendix 2: PhD Project Interview Protocol

Climate Smart Agricultural Technologies (CSATs) related to water use and management in South Africa

An in-depth interviewing methodology will be used to identify and characterise CSATs available in South Africa. The in-depth interviews (IDIs) will be conducted with various actors in agriculture to gather ideas of the technologies that identified actors thought to be appropriate and directed towards smallholder farmers. The interviews will explore the existing and expected CSATs related to water use and management in SA which are both directed at smallholder farmers and are available and/or expected to come in the market in the near future. The following topics/issues/questions will form the core of the interview guide for our IDIs:

Institutions: ____

Interviewee (Title and Name): ______________________________

Interviewer: ____

A. Introduction

B. Survey Section to be Used:

_____ I: Interview Background

_____ II: Institutional Perspective

_____ III: Existing and/or Future Expected water related Climate Smart Agriculture Technologies (CSATs) Assessment

Other Topics Discussed: ___________________________________

Documents Obtained: _____________________________________

*C. Post Interview Comments or Leads:*___________________________________

A. Introduction

We want to thank you for taking the time to meet with us today.

My name is --- and we would like to talk to you about CSATs that exist in South Africa. Particularly, as one of the components of the PhD project on determining drivers and barriers to CSATs adoption we are identifying the water related CSATs that exist in SA and characterizing them based on a contextualized understanding of CSATs directed at smallholder farmers and their different attributes and context of application by farmers. We also want to gain insights about how different technologies are introduced and brought to farmers and your involvement with agricultural technology development and diffusion. You have been selected to speak with us today because you have been identified as someone who has a great deal to share about CSATs in South Africa since you have experience working here and to gain insights it is important for us hear your views and experiences.

We have planned this interview to take 45 minutes to an hour. During this time, we have several questions that we would like to cover. If time begins to run short, it may be necessary to interrupt you in order to push ahead and complete this line of questioning. Although we will be taking some notes during the session, we can't possibly write faster to get everything down. Because we don't want to miss any of your comments we would like to audio tape our conversations today. Please be sure to speak up so that we don't miss any of your comments. We will keep all responses confidential and only the research team members will be privy to the information and we will ensure that any information we include in our research report does not identify you as the respondent. Remember, your participation is voluntary and you don't have talk about anything you don't want to and you may end the interview at any time if you feel uncomfortable. We do not intend to inflict any harm.

Do you have any questions about what we have just explained? Are you willing to participate in this interview? (*If yes, would you please sign below to meet our human subject requirements*).

Interviewee Date

B. Survey Section to be Used (Questions)

I. Interviewee Background

How long have you been …

_______ in your present position?

_______ at this institution?

Interesting background information on interviewee:

What is your highest degree? ________________________________

What is your field of study? _________________________________

1. What does your institution do? (*this can be filled from their website*) ……………………………
2. Briefly describe your role (office, committee, position, etc.) as it relates to agriculture and farmers, technologies for water use and management (if appropriate) …………………………

II. Institutional Perspective

1. What is the strategy at this institution for improving development, diffusion and use of relevant technologies for climate change mitigation and adaptation?..

Probes: Is it working – why or why not?..

2. What resources are available to your institution for improving development, diffusion and use of relevant technologies for climate change mitigation and adaptation ……………………………………

Chapter 8

3. What kinds of networks do you see developing surrounding climate change mitigation and adaptation? *(List them)* …………………………………………………………………………

Probe: Has your institution subscribed to any of the network(s) mention above? (*list them*) ………………

4. What are the potential constraints to improving development, diffusion and use of CSATs encountered in your department? . . …………………………… Institution?...

Probes: How can these barriers be overcomed?...

What are the major opportunities? How can they be maximized?...

5. In your view what is changing (*issues on water quantity and quality*) about availability of water resources for agriculture in this country (South Africa)?...

Probe: What are your past, current and future initiatives related to use and management of water in agriculture (in the face of climate change) and how are they being accomplished? (e.g. Projects/programmes) ………………………………………………………………………………………

III. Existing and/or Future Expected water related Climate Smart Agriculture Technologies (CSATs)

1. List of technologies that are considered CSA technologies and practices which are promoted in SA? (*tick them as they are mentioned and write down additional ones*)

a. Conservation agriculture (Minimum to zero tillage; cover crops; rotation)
b. Water management (Small-scale irrigation; Bunds/zai, tied ridge system; Water harvesting; Terraces, Contour farming)
c. Agroforestry (Live barriers, fences; crops on tree-land)
d. Soil Conservation structures
e. Soil and Water Conservation technologies
f. New traits, Varieties & Crops
g. Others ………………………………………………………………………………………………………

Probe: Which of the above mentioned technologies are related to water use and management that could help crop farmers to mitigate and adapt climate change (CSATs)? (*List them*) ……………………

Probe: What CSA technologies related to water use and management that could help crop farmers to mitigate and adapt climate change have you developed and/or promoted? (*List them*) …………………

Probe: Where in SA have you promoted the technologies and /or execute interventions (if you did) targeted at promoting the adoption of the identified technologies?..

2. Practical questions about the technologies (CSATs) you have developed and/or promoted and/or listed above:

a. What does the technology make? (*factual/actual use for the technology*) ………………………
b. What is its purpose? (*what is designed for*) …………………………………………… ………….

Probe: Does this CSAT have specific environmental objective? (*explain*) ………………………………

c. In your opinion is this technology add-on or integrated; incremental or radical? (*circle what applies*) ………………………………………………………………………
d. Where was the technology produced/manufactured? (*imported/exported*) (*endogenous versus exogenous innovations*) ………………………………………………………………………………

Probe: Do you think CSAT you mentioned above is compatible with existing practices and needs of smallholder farmers?..

e. In your view what do you consider to be the effects of the mentioned technology on the following; product quality, yield of farmers, cost of production and natural resources (i.e. environmental impact) ………………………………………………………………
f. Does this technology deliver significant food security benefits to farmers and/or market potential?...

g. Does this technology hold mitigation and/or adaptation potential?...

Probe: For which farmers (small-scale or large-scale) and under which conditions (humid or dry areas)?.. ....

h. In your view is this technology management intensive or capital intensive; continuous or discontinuous innovation? (*circle what applies and explain*) ……………………………………
i. Does this technology result in saving of labour and/or land?..
j. For this technology, is the focus on individual adopter or group of farmers (land users)? (*explain*) ……………………………………………………………………………………………………..
k. Is this technology considered low-cost or high-cost technology?...
l. Is this technology an embodied, exogenous innovations (EEI) or packages of disembodied agronomic and managerial innovations (PDAMI)?...
m. What is the state of development of this technology? (*matured or non-matured*) ………………..
n. Is the technology applicable to (*site specific*) specific/every region?..
o. Can it be repaired and maintained by an ordinary person?..

3. What CSATs should be adopted by smallholder farmers? *Why*?...

4. How are they/were introduced to farmers and/or implemented? *When*?..

5. Do you recognize any barriers/impediments to the development, diffusion and use of relevant CSATs? (*mention at least 4 which you think are critical*) ……………………………………………………………….

Probes: At what level do you think/see barriers/impediments to the development, diffusion and use of relevant CSATs surfacing? (*from inception and innovation stages to the transfer of technologies and the access to agricultural innovations (CSATs) by smallholder farmers*) …………………………………..

What do you think can be done to address these barriers/impediments? (*mention at least 5 suggestions or recommendations*) ……………………………………………………………………………………………

6. Describe capacities of smallholder farmers that are required to enhance CSATs adoption and successful use. *(mention at least 4 which you think are critical)* ……………………………………………….

7. What types of development opportunities do you see emerging on your institution that focuses on technologies/techniques for climate mitigation and adaptation?..

C. Post Interview Comments or Leads

1. Is there anything more you would like to add regarding your institution and/or CSATs? (*relevant observation*)

2. I'll be analysing the information you and others gave me and during the writing process I may need to contact you again for clarification and further questions which might emerge from the analysis.

3. Thank you for your time and sharing your insights.

Appendix 3: Farmers Survey

Drivers and barriers to the adoption of CSA technologies by smallholder farmers

Introduction: Good day and thank you for agreeing to talk to us and good day! My name is ……………………………………………………………………… I work for/am a student with University of Limpopo/Wageningen University and Research. We are conducting a study on the Drivers and Barriers to the Adoption of CSA technologies by smallholder farmers in South Africa. The study seeks to explore factors influencing farmers' adoption and use of CSA technologies for addressing water scarcity related to climate change. Climate change represents a serious threat to agriculture, requiring increases in resilience to climate impacts and potential reductions in greenhouse gas (GHG) emissions. We need to gain a good understanding of how you make a decision to use different CSA technologies and the basis of your decision…Please be informed that your participation is voluntary; you may choose not to answer any questions or decide to stop the discussion at any time. When responding to the questions please be as honest as possible as we value your opinion as an input that will help researchers and other stakeholders to design and recommend best ways to assist you in future as well as to better target their interventions. Please be assure that your responses will be kept confidential. Are you willing to participate in this study?

Yes 1: Continue Survey or No 2: Stop Survey

Date of the interview:

Country: South Africa

Province: Limpopo

Interviewer: Signature:

Data entry personnel: Signature:

Respondent Number: …………………………………………………………………………

Name of a Respondent: ………………………………………………………………………

Contact of a respondent:……………………………………………………………………..

District: ………………………………………………………………………………………….

Municipality:…………………………………………………………………………………….

Village of a respondent: ……………………………………………………………………….

Section A: Farmers characteristics

A1: Respondent Number…………….

A2: Gender of Respondent

1= Female	2= Male

A3: Marital Status

1= Married	2=Never Married	3= Divorced/Separated	4= Widow/Widower

A4: Age of the Respondent in years (birth year in brackets)

1= <18	2= 18-35	3= 36-45	4= 46-55	5= 56-65	6= >65

A5: Education of the Respondent

1= No Schooling	2= Primary Education	3=Secondary Education	4= Post-Secondary Education

A6: What is your main reason for farming?

1= Produce for family consumption	2= Produce for family consumption and market	3= Extra income	4= Employment creation	5= Recreational	6= Other (Specify)

A7: What is the land size which you use for agricultural purposes in hectares or local measurement unit?..................

A8: How is the land you are using for agricultural purposes registered?

1=Title deed	2= Permission to Occupy (PTO)	3=Lease/Rent land on ≤ 5 years contract	4=Lease/Rent land on ≥ 6 years contract	5=No agreement	6= If other, explain

A9: When did you acquire the land? (*Indicate the year)* ………………………………………

A10: If you bought or pay rent for the land, how much did/do you pay in (Rands/year)? ……………………………

A11: Farmer's livelihood structure: Complete the table below;

Sources of Income	**Tick if farmer gets income**	**Rank in order of importance**
1= Rainfed agriculture		
2= Irrigated agriculture		
3= Livestock and poultry		
4= Formal employment		
5= Remittances from household member elsewhere		
6= Social grant (e.g. pension, foster grant, child support, etc.)		
7= Other informal sources or part-time jobs		

A12: How much is your total income in rand per month?

1= < 700	2= 700-1500	3= 1501-2500	4=2501-3500	5= 3501-5000	6= >5000

A13: What do you estimate to be your agricultural income per month?...

A14: What are the main crops grown by the farmer? a) …………………b) ……………….………

c) …………………………….. d)………………………… e) ……………………………

For each of the crops produced, explain the following;

Crop	Is the crop for sale or home consumption	If sold, do you sell less or more than half?	Where is the crop sold?	What are the 2 main challenges in growing the crop?

A15.1: What is the type of seeds you use for your maize and/or sorghum?

1= Hybrids	2= Open Pollinated Varieties (OPVs)	3= Other (Specify)

A15.2: What informs you to choose the above type of seeds?

1= Advice from extension officers	2= Advice from other farmers	3= According to expected yield?	4= Other (Specify)

A15.3: How do you usually get maize/sorghum seeds?

1= Self-purchased seeds	2= Government Seed Provision Scheme (i.e. LDA)	3= Farm saved	4= Cooperative or Farmer association	5= Exchange	6= Other (Specify)

A16: How do you usually get fertilizers/agrochemicals (insecticide/herbicides)?

1= Self-Purchased fertilizer/agrochemicals	2= Farmer association	3=Private Company arrangement	4= Government Provision Scheme	5=Other (Specify)

A17: Where do you get your agricultural equipments?

1= Rent from locals	2= Government Scheme	3= Farmer Association	4= Own them	5= Other (Specify)

A18: What is your normal source of credit for agricultural purposes?

1= Formal Financial Institutions	2= Input Supplier	3= Government Scheme	4= Farmer Association	5= Stokvel or Saving Group	6= Loan Shack (Matshonisa)	7= Other (Specify)

A16: What are the main livestock kept by the farmer? a) …………… b)…………… c) …………………..

For each of the livestock kept, explain the following;

Livestock	Is the livestock for sale or for keeping	If sold, do sell less or more than half?	Where is the livestock sold?	What are the 2 main challenges in keeping the livestock?

Section B: Institutional Support

B1: Do you receive any form of government support, extension advice?

1= Yes	2= No

B2: If yes in B1, what type of support and advisory service do you receive from Government extensionist? (*Can choose more than 1 response*)

1= Production and Marketing Information	2= Weather information	3= Information on new technology (i.e. CSA technologies)	4= Finance	Other (Specify)

B3: Have you benefited from any (or different) government programs for Agriculture?

1= Yes	2= No

B4: If yes in B3, Indicate the name of program(s)

1. ………………………………………………………………………………………………………

2. ………………………………………………………………………………………………

3. ………………………………………………………………………………………………

B5: What is the distance in km to the nearest Agricultural Service Centre (Department of Agriculture)? ………..

B6: Do you experience any challenges concerning the government extension services? (Specify)

………..

B7: Are you a member of a farmers' organisation?

1= Yes	2= No

B8: If yes in B7, which organization? (*Specify the name*).……………………………………………

B9: Are you a member of a commodity group?

1= Yes	2= No

B10: If yes in B9, what kind of a commodity group? (*Specify the type*) …………………………… ………..

What benefits do you receive from participating in farmers organisations and/or commodity group?(*Specify*)
…..

B11: Do you receive any form of Private Sector, NGO and/or Universities/ Research Institutions support?

1= Yes	2= No

B12: If yes in B11, what type of support and advisory service do you receive? from Private Sector? (*Explain*)
………

Section C: Farmers' Knowledge on Climate Change and CSA Technologies and Practices

C1: Definition of climate change: According to you (i.e. farmer) what is climate change?

1= Change in rainfall pattern	2= Change in rainy season pattern	3= Change in rainy season duration	4= Change in drought season pattern	5= Change in drought duration	6= Change in daily temperature

C2: Do farmers experience climate change and if yes how?

C2.1: Did/do you experience climate change?

1= Yes	2= No

C2.2: If Yes in B2.1, what climate change signs do you perceive risky?

Climate change signs do you perceive risky	List them from the most important to less ones
1= Increasing of daily temperature	
2= Delay in rainfall starting	
3= Early rainfall starting	
4= Early end of rainy season (i.e. shorter rainy season)	
5= Temporary drought period appearing during rainy season	
6= Irregular flood	
7= Recurrent flood	

C3: According to you what are the effects of climate change on your production systems (crops and animals)? (List them from the most important to the less ones).

C3.1: Consequences on cropping systems:

Consequences on cropping systems:	List them from the most important to the less ones
1= Decreasing yields	
2= Low growing rate of seeds	
3= Increased mortality rate of plants	
4= Incomplete life cycle of crops	
5= Increasing soil erosion	
6= Increase in weed pressure	

C3.2: Consequences on animals and livestock systems:

Consequences on animals and livestock systems:	List them from the most important to the less ones
1= Shortage of pasture	
2= Longer days to look for green fodder for animals due to less crop biomass	
3= Increase mortality of animals	
4= Increase diseases	

C4: According to you what are the effects of climate change on your livelihood structure? (List them from the most important to the less ones)

Undesirable consequences on farmers livelihood structures	**List them from the most important to the less ones**
1=Increase production cost	
2=Decrease revenue	
3=Increase poverty	
4=Decrease in food availability	
5=Increase in nutritional and food insecurity	
6= Increase demand on family labour	
7= Increase demand for hired labour for weeding	
8= Replanting of crops to fill gaps	
9=Increase in rest period	

C5: What do farmers do to cope with the effects of climate change? (e.g. in terms of crop and water management technologies?

Different strategies you use to cope with the climate change	**List them (strategies) from the most used to the less one**
1= Adjustment of soil preparation period (late or early ploughing)	
2= Adjustment of sowing period (staggered planting; early or late sowing	
3= Adjustment of soil preparation method (zero ploughing/ No till, no soil preparation)	
4= Use of short cycle varieties	
5= Use of drought tolerant varieties	
6= Adjustment of planting method (transplanting, ridge planting)	
7= Harvesting Rainwater	
8= Crop diversification	

C6: What technologies do farmers know or foresee that will help them to address the negative effects of climate change? (CSA technologies)

CSA technologies and practices that you know and foresee to use? For each of them complete the table:

CSA technologies & practices	**Tick the ones you know**	**Who introduced them to you/ how did you come to know about them?**	**Tick the ones you use**	**Tick the ones you foresee to use**

Drought tolerant and early maturing varieties				
Agroforestry				
Conservation Agriculture				
IRWH				
Mechanized basins				
Intercropping				
Biochar				

Section D: Farmers' Perceptions of the CSA Technology Specific Attributes (The respondents of the interviews could choose their opinions about the characteristics and important effects of CSA technologies from a list, which include 35 possible statements)

Drought Tolerant and Fast Maturing Maize/Sorghum Cultivars

Item	**Perceptions of the CSA Technology Specific Attributes**	**Strongly Disagree (1)**	**Disagree (2)**	**Neutral (3)**	**Agree (4)**	**Strongly Agree (5)**
D1.1	I have knowledge about drought tolerant and fast maturing cultivars					
D1.2	I have had adequate training on planting of drought tolerant and fast maturing cultivars					
D1.3	I currently have adequate opportunities for training related to drought tolerant and fast maturing cultivars in my area (village/project)					
D1.4	Drought tolerant and fast maturing cultivars have been well demonstrated in my area					
D1.5	I have knowledge on better planting date for drought tolerant and fast maturing cultivars in my area					
D1.6	I have all the ability and resources to inform me about weather forecast in my area					
D1.7	I have adequate access to Agricultural advisory services regarding drought tolerant and fast maturing cultivars					

D1.8	I have adequate finance to plant drought tolerant and fast maturing cultivars productively					
D2.1	Planting drought tolerant and fast maturing cultivars enable extra yield to be realized					
D2.2	Planting Drought tolerant and fast maturing cultivars enable increased income to be realized					
D2.3	Planting Drought tolerant and fast maturing cultivars safeguard household food availability					
D2.4	Planting Drought tolerant and fast maturing cultivars have the ability to decrease negative environmental (climate change) impacts (e.g. water scarcity)					
D2.5	Planting Drought tolerant and fast maturing cultivars have the ability to decrease costs of fertilizers and herbicides/pesticides					
D2.6	Planting Drought tolerant and fast maturing cultivars require additional labour force					
D2.7	Planting Drought tolerant and fast maturing offers immediate benefits					
D2.8	Planting drought tolerant and fast maturing cultivars changes working time					
D2.9	Planting drought tolerant and fast maturing cultivars changes my planning process (e.g. planting dates)					
D2.10	Planting drought tolerant and fast maturing cultivars is management intensive (e.g. birds watching to protect seeds)					
D3.1	It is easy to produce drought tolerant and fast maturing cultivars					
D3.2	I will be able to buy seeds that are drought and fast maturing cultivars					
D3.3	I will be able to pay for/hire a tractor to plough my field to plant drought tolerant and fast maturing cultivars					
D3.4	I will be able to acquire all the resources (inputs/implements and labour) required to plant drought tolerant and fast maturing cultivars					
D4	I am prepared to plant drought tolerant and fast maturing cultivars					
D5	I am prepared to tell (or share my knowledge) other farmers					

	about drought tolerant and fast maturing cultivars					
D6.1	It is important to be informed about weather information (i.e. temperatures and rainfall) in my area					
D6.2	It is important to know about better planting date for drought tolerant and fast maturing cultivars					
D6.3	It is important to receive seeds for drought tolerant and fast maturing cultivars through government scheme					
D6.4	It is important to have a local supplier of seeds for drought tolerant and fast maturing cultivars					
D6.5	It is important to receive tractor services on time to plant drought tolerant and fast maturing cultivars					
D6.6	Additional training would increase my knowledge about drought tolerant and fast maturing cultivars					
D6.7	Additional training would increase my ability to adopt drought tolerant and fast maturing cultivars					
D6.8	Observation of the benefits of CSA technologies from my neighbours (other farmers) would increase my ability to adopt them					
D6.9	To be engaged during developmental phase of CSA technologies would increase my ability to adopt them					
D6.10	I can change from planting at my usual dates if am informed about best planting dates in my area					
D6.11	I consider knowledge about the other cultivars important					
D6.12	I consider knowledge about other CSA technologies and practices important					
D6.13	Information about other CSA technologies would increase my ability to adopt them					
D7.1	I have knowledge on non-agricultural activities that could sustain my life better					
D7.2	I consider knowledge about other activities other than agriculture important					
D7.3	I can switch from agricultural production to exercise other activities if am informed about them					

D7.4	I have a relevant expertise and/or experience to get the job elsewhere					

In-Field Rainwater Harvesting (IRWH) Technology

Item	Perceptions of the CSA Technology Specific Attributes	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
D1.1	I have knowledge about in-field rainwater harvesting (IRWH) technology					
D1.2	I have had adequate training on IRWH technology					
D1.3	I currently have adequate opportunities for training related to IRWH technology in my area (village/project)					
D1.4	IRWH technology have been well demonstrated in my area					
D1.5	I have knowledge on better planting date using IRWH technology in my area					
D1.6	I have all the ability and resources to inform me about weather forecast in my area					
D1.7	I have adequate access to Agricultural advisory services regarding IRWH technology					
D1.8	I have adequate finance to adopt/implement IRWH technology productively					
D2.1	Adopting IRWH technology enable extra yield to be realized					
D2.2	Adopting IRWH technology enable increased income to be realized					
D2.3	Adopting IRWH technology safeguard household food availability					
D2.4	Adopting IRWH technology have the ability to decrease negative environmental (climate change) impacts (e.g. water scarcity)					
D2.5	Adopting IRWH technology have the ability to decrease costs of fertilizers and herbicides/pesticides					
D2.6	Adopting IRWH technology require additional labour force					
D2.7	Adopting IRWH technology offers immediate benefits					
D2.8	Adopting IRWH technology changes working time					
D2.9	Adopting IRWH technology changes my planning process (e.g. planting dates)					
D2.10	Adopting IRWH technology is management intensive (e.g. constructing/reinforcing basins)					

D3.1	It is easy to adopt IRWH technology					
D3.2	I will be able to buy/acquire seeds plant my field and to utilize harvested rainwater					
D3.3	I will be able to pay for/hire a tractor to plough my field and to utilize harvested rainwater					
D3.4	I will be able to acquire all the resources (inputs/implements and labour) required to adopt IRWH technology					
D4	I am prepared to adopt IRWH technology					
D5	I am prepared to tell (or share my knowledge) other farmers about IRWH technology					
D6.1	It is important to be informed about weather information (i.e. temperatures and rainfall) in my area					
D6.2	It is important to know about better planting date when adopting IRWH technology					
D6.3	It is important to receive seeds and implements through government scheme when adopting IRWH technology					
D6.4	It is important to have a local supplier of seeds and implements related to when adopting IRWH technology					
D6.5	It is important to receive tractor services on time to adopt IRWH technology					
D6.6	Additional training would increase my knowledge about IRWH technology					
D6.7	Additional training would increase my ability to adopt IRWH technology					
D6.8	Observation of the benefits of CSA technologies from my neighbours (other farmers) would increase my ability to adopt them					
D6.9	To be engaged during developmental phase of CSA technologies would increase my ability to adopt them					
D6.10	I can change from planting at my usual dates if am informed about best planting dates in my area					
D6.11	I consider knowledge about the other rainwater harvesting technologies (methods) important					
D6.12	I consider knowledge about other CSA technologies and practices important					

D6.13	Information about other CSA technologies would increase my ability to adopt them					
D7.1	I have knowledge on non-agricultural activities that could sustain my life better					
D7.2	I consider knowledge about other activities other than agriculture important					
D7.3	I can switch from agricultural production to exercise other activities if am informed about them					
D7.4	I have a relevant expertise and/or experience to get the job elsewhere					

Thank you for your time and participation! If you would like to receive results of this research or you have other questions, please do not hesitate to contact the principal researcher:

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Summary

Globally, there is a recognition of the need to reconcile environmental protection, invest in smallholder agriculture, reduce carbon emissions, improve food production and productivity and reduce vulnerability to the predicted impacts of climate change. In sub-Saharan Africa (SSA), agriculture forms part of the local economies. The agricultural sector is a source of food security and livelihood for many poor people in rural communities, making it necessary to safeguard livelihoods of rural smallholder farmers. Nevertheless, smallholder agriculture in Southern Africa is extremely vulnerable to climate variability and change, for instance extreme weather events such as floods, drought and heat waves. South Africa's agricultural sector faces a scarcity of water, which will increase as a result of climate change. About two-thirds of South Africa is arid or semi-arid, which means that efficient management of water resources is a national priority. Numerous researchers in South Africa indicated existing and potential water-related impacts of climate change, thereby warranting exploration of interventions required to reduce the consumption and to manage supply in order to safeguard water security for the agricultural sector. A proposed means promoted as way to address these challenges is Climate smart agriculture (CSA), aimed at achieving sustainable agricultural development for food security under climate change. CSA technologies at farm level have the potential to address these challenges but they are not adequately adopted. Sufficient insights are needed on barriers to adoption and how those barriers influence the adoption of potential technologies and practices. Understanding technologies and practices that farmers favour or disfavour regardless of their struggle to adapt to extreme weather events associated with climate change and variability is crucial to inform transformation of Africa's agriculture in the face of climate change. This thesis, therefore, argues that data on CSA in the context of South Africa is also necessary to foster CSA take-off on the African continent. Considering this argument and knowledge gap, this thesis posed the following general research question:

What restricts the adequate adoption of high potential CSA technologies in South Africa and how can adoption of CSA technologies by the smallholder farmers be enhanced?

The objective of this thesis is to analyse the relevance of socio-economic analysis for supporting CSA technologies and decision-making practices, and in particular the importance of understanding the drivers and barriers to the adoption of CSA technologies in smallholder farming practice. In this effort, we focus on the perspective of technology providers and smallholder farmers and their contributing to the dissemination and adoption of CSA.

In this study, four empirical studies were employed to answer the general question. A combination of the demand-supply perspective and the multi-method approach were used to understand the adoption of CSA technologies.

Chapter 2 serves as an initial assessment to understand the context of CSA Technological Innovations in South Africa. Whilst the impacts of climate change are undeniable and the importance of CSA agriculture is recognized, previous research focused on the impact of climate change on South African Agriculture, its sensitivity to climate change and on the decreasing water resources available. Clear knowledge gaps exist in relation to how socio-economic and other factors impact CSATIs adoption and diffusion in South Africa. For these reasons, understanding how the socio-economic conditions interact with the characteristics of CSA technologies and practices formed part of this research. In response to this gap, the study conducted in Chapter 2 of this thesis was necessary given that exploration of the characteristics of CSA technologies is the first step to understand their adoption. Thus, Chapter 2 answers the following research question"

Research question 1 (Chapter 2): *What is the specific potential of CSA technologies related to water use and management available in South Africa, and what are their characteristics, their context of application, and their potential to address climate change?*

This chapter illustrated the importance of understanding the role of the characteristics of the technologies in question when analysing decision-making of farmers when responding to climate change impacts. Based on a literature review and semi-structured interviews with several stakeholders, including governmental officials, researchers from state-owned research institutions and universities, companies, farmer organisations and NGOs (N=27), the study explored the key characteristics of the available CSATIs, and how these characteristics may impact their adoption in the context of South Africa. We found that Conservation Agriculture (CA), Rain Water Harvesting (RWH) and Seed Varieties that are Drought Tolerant and Early Maturing (DTSVs) seemed to be the most suitable technologies and practices for the South African context. However, high initial investment costs and additional labour requirements, as well as intensive management attention associated with CA and RWH, might render these technologies less advantageous for smallholder farmers. DTSVs, especially the Open Pollinated Varieties (OPVs), were noted to be less costly, not management intensive, and therefore could present better prospects of adoption by smallholder farmers. These results suggest that technology selection is not purely dependend on contextual factors. Thus, other socio-economic factors such as costs and skills play a role in decisions regarding technology adoption.

Following the analysis of several SCATIs to address the climate change related challenges in Chapter 2, Chapter 3 explores the reasons behind the low adoption of these technologies from the farmers' perspective. The following research question was addressed:

Research question 2 (Chapter 3): *What are the drivers and barriers to the adoption of drought-tolerant seed varieties as an example of a CSA technology and how can opportunities be created to assist farmers in implementing CSA in general and in adopting DTSVs in particular?*

To answer this research question, a survey method was employed. Five focus group discussions (N=45) preceded a survey comprising a sample size of 196 smallholder farmers. Our findings showed that smallholder farmers in the study were using three seed varieties: Hybrids, OPVs (i.e. DTSVs) and Traditional seeds. In most cases, they used more than one seed variety in one season and in one field. The variables "Training and demonstration related to DTSVs", "Knowledge possession and benefits related to DTSVs" and "Enabling factors" were found to be significant predictors, suggesting that adequate opportunities for training and extension support, training, demonstrations of technologies, together with supporting elements such as information and additional training regarding the DTSVs had an influence on whether farmers used "Hybrids and Hybrids with either Open Pollinated Varieties (OPVs) or Traditional seeds". Remarkably, farmers raised trust related concerns regarding production and marketing of quality seeds at the local level. Moreover, those farmers were more vocal about access to credit than they were about seeds provision by the government.

Departing from the premise that adoption and diffusion of CSATIs is impacted by both supply and demand factors, and considering that few studies explored the interrelations between supply and demand side barriers, Chapter 4 focuses on understanding the supply-side barriers from the perspectives of the agri-technology providers by examining their business models. In this chapter, the aim is to answer the following question:

Research question 3 (Chapter 4): *What are the factors that affect the ability of CSA technology providers to diffuse CSATIs to smallholder farmers at the base-of-the-pyramid (BoP)?*

To address research question 3, face-to-face semi-structured interviews among 10 agri-technology providers served as research material. Our results revealed that existing business models of the agri-technology providers do not seem to be functioning optimally to diffuse CSATIs in targeting smallholder farmers. While access and provision of different CSA technologies such as DTSVs motivate the farmers to adopt the seeds, inadequate technical know-how, lack of storage facilities, risk of underpayment in case of fixed-contracts, as well as the lack of freedom to make independent decisions regarding the sale of their produce tend to inhibit adoption by smallholder farmers. This shows the significance of product-service system strategies.

While our empirical findings were largely consistent with key factors identified within the literature, two distinctive viewpoints related to BoP contexts were identified. Thus, our results revealed that for smallholder farmers within a BoP context, an effective value proposition alone is not sufficient to enhance adoption. Second, our findings indicated that the core requirement of smallholder farmers within the BoP goes beyond proof of impact (as it is the case in western contexts), and includes a need for production credit. Therefore, this chapter provides important practical implications for managers of agri-technology businesses and necessary groundwork for future research to explore different specific types of support that will constitute their business model innovations.

Chapter 5 went further to investigate the impact and efficacy of interventions designed to increase technology adoption.

Research question 4 (Chapter 5): *What is the efficacy of the Water Efficient Maize for Africa (WEMA) project in South Africa as an intervention designed to increase technology adoption by smallholder farmers?*

To answer research question 4, this thesis took a case study approach. Water Efficient Maize for Africa (WEMA), a PPP with the objective to improve food security and rural livelihoods among smallholder maize producers in sub-Saharan Africa by developing and disseminating the seed technologies which are drought-tolerant and insect-pest-protected, was identified as a case. The WEMA case enabled us to demonstrate how PPPs work in practice by highlighting some of the successes attained and the challenges that prevailed, as well as the implications for theory and practice. For example, the WEMA case showed the need for collaboration between the public (government) and private sector (agri-technology providers) in implementing product-service offerings that have prospect of enhancing the adoption of CSATIs, as smallholder farmers need a package of CSATIs and it appears that agri-technology providers, although willing to partake in the services, are not yet ready to bear all the costs.
Numerous practical implications for policy makers and managers of agri-technology providers can be drawn from this thesis as a whole. First, we observed that training and demonstration were significant in impacting adoption of DTSVs as an example of CSATIs relative to traditional seeds. In this case, policymakers on their own or in partnership with other stakeholders, can mobilize resources and coordinate efforts to provide training and demonstration to farmers regarding the DTSVs. However, government support of education, training and assistance

related to CSA technologies should be tailored to suit farmers' different needs and capabilities, since our results highlighted that smallholder farmers are heterogeneous, with some having better capabilities to adopt CSA technologies. Second, tender-preneuring as a procurement method is susceptible to corruption, due to the exorbitant mark-ups charged by the tender-preneurs to government, thereby inflating government costs of interventions. Therefore, policy makers can choose to shun away from this tender-preneur approach in procurement of CSATIs or reconsider the procurement system by including intensified monitoring and evaluation to prevent the kind of irregularities noted by our respondents. The agri-technology providers observed that product-service systems have a better prospect to enhance adoption of CSATIs since smallholder farmers need a package of CSATIs to implement CSA adequately. Agri-technology providers, although willing to partake in the services, are not yet ready to bear all the costs. Therefore, in this instance, governmental intervention in a multi-actor based business model could be the driver that can enable farmers to buy and/or pay for CSATIs.

Some respondents in our study noted that Agroforestry should be among the prioritised CSATIs, yet literature shows that technologies like Agroforestry involve radical change, suggesting it is less likely to be adopted as compared to incremental technologies like new seed varieties. Therefore, future research could explore the conditions under which radical technological innovations would be most appropriate and what forms of support may be needed. It is also likely that combinations of technologies may be needed to achieve better results with CSA efforts, so future research could also investigate how this occurs in practice. The outcome of our case study indicatively suggests that the way of doing business between the smallholder farmers and the private sector is not yet normal in the sense that perhaps the levels of productivity are currently nowhere near the requirement of most private sector players to be interested in dealing with smallholder farmers. Future research can explore what specific capacities are necessary for what type of farmers to make them real partners for technology providers.

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Mmapatla Precious Senyolo,

06 January 2020

Mankweng, Polokwane, South Africa

About the author

Mmapatla Precious Senyolo was born on 02 August 1985 in Mankweng, Polokwane, South Africa. She attended high school at Hwiti Secondary School and Matriculated at Radikgomo Secondary School. She earned a BSc. in Agricultural Economics from the University of Limpopo in 2007. In 2008 She obtained a Diploma in Agricultural Research for Development from the International Centre for Development Oriented Research in Agriculture (ICRA) in the Netherlands. In the same year she obtained a Scholarship from the Netherlands Organization for International Cooperation in Higher Education (NUFFIC) through NFP Project to pursue her MSc Degree from Wageningen University. She then obtained an MSc in Environmental Economics from Wageningen University on the 23rd September 2010. During her MSc degree she did a 4 months' internship with Limpopo Economic Development and Tourism (LEDET) in South Africa during her field work. From August 2010, she joined the University of Limpopo in South Africa as a lecturer in the Department of Agricultural Economics. In 2012 she was awarded a South African Agricultural Economics Fellowship Programme to the USA by the South African National Agricultural Marketing Council coordinated by Cornell University in the USA. In 2013 she was awarded a sandwich PhD scholarship by NUFFIC to pursue her PhD at Wageningen University. In the course of her PhD she also lectured Master of Development students at the Turfloop Graduate School of Leadership, Edupark Campus of University of Limpopo. Results of her PhD research have been presented at international conferences, published in peer reviewed journal articles. Overall, during her PhD studies she remained the employee of the University of Limpopo in South Africa as a Lecturer and Researcher. Her research interests include Socio-economic analysis in general, Climate-smart agriculture, Value chain analysis, Food security analysis, Livelihood and Gender analysis, Resource Efficiency and Natural Resource Management issues.

Publications

Peer reviewed publications

Mmapatla Precious Senyolo, Thomas B. Long, Vincent Blok, and Onno Omta (2018). "How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa.": published in *the Journal of Cleaner Production* 172 (2018): 3825-3840. https://doi.org/10.1016/j.jclepro.2017.06.019

Under review / Submitted

Mmapatla Precious Senyolo, Thomas B. Long, Vincent Blok, Onno Omta and Gerben van der Velde (2019). " Smallholder adoption of technology: evidence from the context of climate smart agriculture in South Africa". Submitted to *International Journal of Agricultural Sustainability.*

Mmapatla Precious Senyolo, Thomas B. Long, Vincent Blok, and Onno Omta. "Climate-smart agriculture diffusion in bottom-of-the-pyramid contexts: the role of business models of Agri-technology providers". Under-review with the *International Food and Agribusiness Management Review Journal.*

Mmapatla Precious Senyolo, Thomas B. Long, and Onno Omta. "Enhancing the adoption of climate-smart technologies using public-private partnerships: Lessons from the WEMA case in South Africa". Under-review with the *International Food and Agribusiness Management Review Journal.*

Presented Conference Papers

Drivers and barriers to the adoption of Climate-smart Agriculture (CSA) technologies by smallholder farmers in South Africa". *Research Proposal presented in June 2015 at the Limpopo Department of Agriculture Research Forum, Polokwane, South Africa.*

How the characteristics of technology affect adoption by smallholder farmers: evidence of CSA from South Africa. *Paper presented in November 2015 at the Global Cleaner Production and Sustainable Consumption Conference, Sitges, Barcelona, Spain.*

Drivers and barriers to the adoption of CSA technologies by smallholder farmers: evidence from South Africa. *Paper presented in June 2016 at the combined 26th IFAMA World and 12th WICaNeM Conference, Aarhus, Denmark.*

Marketing Channels and Value Chain Analysis Towards Poverty Reduction in the Smallholder Agriculture. *Paper presented in October 2017 at the Department of Agriculture, Forestry and Fisheries (DAFF) Research Seminar, Pretoria, South Africa.*

Mmapatla Precious Senyolo
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Writing Research Proposal	WASS	2014	6
Advanced Supply Chain Management	WUR	2014	1
Systematic Approaches to Reviewing Literature	WASS	2014	4
Negotiating environmental limits	WASS	2014	1
Conceptual foundations of modern environmental governance	WASS	2014	1
Entrepreneurship in Emerging Economies	WASS	2018	2
"*Drivers and barriers to the adoption of Climate-smart Agriculture (CSA) technologies by smallholder farmers in South Africa*"	Limpopo Department of Agriculture Research Forum, Polokwane, South Africa	2015	1
"How the characteristics of technology affect adoption by smallholder farmers: evidence of CSA from South Africa"	Global Cleaner Production and Sustainable Consumption Conference, Sitges, Barcelona, Spain	2015	1
"*Drivers and barriers to the adoption of CSA technologies by smallholder farmers: evidence from South Africa*"	Combined 26th Annual IFAMA World Conference and 11th WICaNeM conference, Aarhus, Denmark	2016	1
"Marketing Channels And Value Chain Analysis Towards Poverty Reduction In the Smallholder Agriculture"	Department of Agriculture, Forestry and Fisheries (DAFF) Research Seminar, Pretoria, South Africa	2017	1
B) General research related competences			
WASS Introduction course	WASS	2014	1
Research Methodology: From topic to proposal	WASS	2014	4
Introduction to R for Statistical analysis	PE&RC	2014	0.6
Qualitative Data Analysis with Atlas.ti	WASS	2014	1
Techniques for writing and presenting scientific papers	WGS	2015	1.2
C) Career related competences/personal development			
Competence Assessment	WGS	2014	0.3
Information literacy PhD including Endnote Introduction	WGS	2014	0.6
Scientific Publishing	WGS	2015	0.3
Research Data Management Planning	WGS	2015	0.15
Reviewing Proposals for National Research Funding (NRF) in South Africa	NRF, South Africa	2017	0.7
The Essentials of Scientific Writing and Presenting	WGS	2018	1.2
Reviewing a Scientific Paper	WGS	2018	0.1
Critical thinking and argumentation	WGS	2018	0.3
Reviewing a Scientific Paper for International Food and Agricultural Management Review (IFAMR) journal	IFAMR	2019	0.3
Performance Management	Turf loop Graduate School of Leadership, UL, South Africa	2019	0.6
Shadow Head of Department during Shadowing of Management Positions by Women at UL	University of Limpopo, South Africa	2019	2
Total			**33.45**

*One credit according to ECTS is on average equivalent to 28 hours of study load
WUR = Wageningen University and Research, WASS = Wageningen School of Social Science, WGS = Wageningen Graduate School, PE&RC = Production Ecology and Resource Conservation

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