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Smart Farming for a Secure Future: Balancing Climate Smart Solutions & Enhancing Food Security in Ethiopia

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By Emma Mayhew

Abstract

In the face of climate change impacts, Ethiopia grappling with the imminent threat of famine and food insecurity. The agricultural sector, crucial to the nation's economy, is especially vulnerable. This underscores the importance of gaining a deeper understanding of the complexity of food security and potential solutions in Ethiopia. This research investigates the possibility of integrating Climate Smart Agriculture (CSA) solutions to boost food security in the country. In light of the growing prominence of digital solutions in agriculture and aligned with the government's 'Digital Ethiopia Strategy 2025', the research places particular emphasis on discerning the potential of high- and low-tech solutions in the country. High-tech solutions are defined as advanced technologies like precision agriculture, modified crops and digital services; and low-tech approaches as practices such as sustainable land use techniques and water storage. Using the socio-technical-ecological systems (STES) framework, it aims to explore the readiness and broader implications for these solutions. A spatial analysis is conducted to measure digital readiness, existing agricultural services, and the state of food security in each administrative zone. Subsequently, a qualitative survey, involving experts, broadens the investigation. It advocates for the integration of high- and low-tech solutions, deeply rooted in local contexts and socio-technical-ecological realities. Barriers to CSA adoption, such as access, affordability and socio-cultural influences underscore the need for using adaptive governance and participatory, bottom-up strategies. The study emphasizes the indispensable role of flexibility, and community consultation in shaping place-based CSA initiatives, with low-tech approaches forming the foundation complemented by improved digital literacy and improved access to information. The study calls for further reflection on self-sufficiency, sovereignty, and food sustainability to enhance existing plans and advocates for a shift towards broader metrics of success.

Keywords: *Climate Smart Agriculture, Food Security, Ethiopia, High-Tech Solutions, Low-Tech Solutions, Socio-Technical-Ecological Systems, Adaptive Governance, Climate Adaptation.*

1. Introduction

Agriculture is the backbone of many African countries and holds significant implications on the status of food security and poverty in the region (Li & Wang, 2016). Despite the significant growth in agricultural production value in Sub-Saharan Africa since 2000, productivity and food security remain lower than required to sustain the region's growing population (Jayne & Sanchez, 2021; Plaizier, 2016; Li & Wang, 2016; Modi, 2019). Furthermore, the region faces challenges such as land tenure insecurity, degrading ecosystems, poor market access, gender inequality, inadequate funding and infrastructure (Williams et al. 2015). With 48.8% of the African population engaged in agriculture (FAO, 2021) contributing to around 25% of GDP, enhancing agriculture is imperative (OECD and FAO, 2016). While some institutions assert that Africa makes up 65% of the world's global arable land (African Development Bank, 2019; Plaizier, 2016; UNDP, 2024), studies highlight that the potential for cropland expansion in Africa is conditional and varies based on several factors, including population density, economic viability, and environmental costs (Chamberlin et al., 2014; Lambin et al., 2013). Additionally, experts agree that increasing productivity on *existing* agricultural land is the best strategy to minimize environmental damage, such as greenhouse gas emissions and biodiversity loss, which are associated with converting new land to agriculture (Hertel, 2011; Deininger and Byerlee, 2011). Given these constraints, it becomes essential to explore innovative approaches to further enhance productivity in the region and potential to transform the agricultural system in Africa.

Ethiopia has faced major food security challenges in the past few decades (Mohamed, 2017; Ocho et al., 2017; Peng et al. 2021; Asrat & Anteneh; 2020). A large portion of the agricultural sector is reliant on smallholder farmers and rainfed agriculture, which is heavily susceptible to the risks posed by climate change (Mohamed, 2017; World Bank 2020). However, the country is amidst an agricultural transition, shifting from traditional agricultural practices to modern, technology-driven, and sustainable agricultural systems (The Ministry for Agriculture and Natural Resources, 2017). Previously, farmers in Ethiopia were heavily dependent on subsistence agriculture, with farmers growing a limited range of crops for their livelihoods.

To diversify farming practices, the government, along with various stakeholders are implementing reforms and interventions to improve agricultural productivity and sustainability (Agricultural Transformation Agency, 2021; Tamene and Ashenafi, 2022). The agricultural transition in Ethiopia is fostering rural development and promoting climate-smart agricultural practices. This includes a heightened use of drought-tolerant crop varieties, improved water management techniques, and the utilization of climate information services (Agricultural Transformation Agency, 2021; Zerssa et al. 2021; Tamene and Ashenafi, 2022). As a result, farmers are more prepared to adapt to changing climatic conditions and reduce their vulnerability to climate change. The Government of Ethiopia is embracing a digital-led development strategy, outlined in the Digital Ethiopia Strategy 2025 (The Federal Democratic Republic of Ethiopia, 2020). This will involve integrating digital agriculture to foster climate-smart agriculture and build capacity and resilience of Ethiopian farmers. Central to this strategy is the envisioning of an integrated agricultural value chain facilitated by digitalization, wherein Digital Climate Advisory Services (DCAS) play a pivotal role are anticipated to modernize and improve farming techniques. It will provide technical optimization of value-chains and food systems, including services such as seasonal and in-season forecasts and agro-advisory information, market information, credit information, insurance information and information on improved technology (The Federal Democratic Republic of Ethiopia, 2020). However, the success of this digital transition hinges on farmers' readiness to embrace technology and the socio-ecological implications thereof.

Despite these plans, there exists a notable research gap in understanding the socio-technical-ecological dynamics of Ethiopia's agricultural landscape. While digitalization hold promise to increase efficiency, the effectiveness in considering the different needs and capacities of local smallholders remains underexplored. In light of this, this research draws on socio-technical-ecological systems framework to develop a comprehensive understanding of Ethiopia's agricultural landscape. It maps the existing social and technical support structures and assesses the digital readiness and food security status in microregions in the country.

This paper defines high-tech solutions as solutions involving advanced technologies to enhance agricultural productivity and sustainability. For example, include precision agriculture, modified crops, climate modelling and digital services such as e-extension, market and weather information. Whereas low-tech approaches utilize sustainable land use techniques and local knowledge to improve agricultural practices. Such as conservation tillage, agroforestry, residue management, intercropping, crop rotation, water storage and incorporating traditional knowledge. It aims to understand how to effectively balance and prioritise high-tech and low-tech solutions to boost food security and empower smallholders and vulnerable communitiesThis is done by digging into the socioecological and technical implications for using hi-tech and low-tech climate smart agricultural. By bridging this gap, this research aims to offer practical recommendations and strategies to promote a resilient and sustainable agricultural future in Ethiopia and beyond.

2. Literature Review & Conceptual Framework

2.1 Reimagining Agri-Food Systems: Towards Sustainable and Inclusive Food Security

> "*A central concern in recent debates about achieving global food security is the need to reconfigure and transform agri-food systems in a way that is better aligned with aspirations for sustainable and socially inclusive patterns of food production and consumption.*" (Conti et al., 2021: 1)

Technical and institutional innovations over the past decades have brought about major advances in human development but in many cases at the cost of the environment. Over the last century agri-food systems have had dramatic consequences for the climate, environment, public health and social justice (Barrett et al. 2022). For example, agriculture has had profoundly negative effects on biodiversity through the fragmentation of natural habitats and pollution due to the overuse of pesticides and fertilizers (Scherr & McNeely, 2008). Biodiversity loss is one of the most critical environmental concerns with far-reaching implications for the health and resilience of ecosystems and livelihoods worldwide (Vermunt et al., 2020). Furthermore, population growth and increasing food demand, coupled with biodiversity loss and climate change, means meeting the demand for food will put "unprecedented pressure on water, land genetic and atmospheric resources" (Barrett et al.

2022: 2). Food systems are failing in four fundamental areas; rising obesity, undernutrition, environmental degradation and food waste (Bilali et al., 2018). Additionally, concerns over the resilience to adverse weather, environmental, economic and political shocks necessitate a shift in agri-food systems. Agri-food systems need a transition and reorientation from economic productivity to prioritise healthy and prosperous people and planet (Willet et al. 2019). Thus, food security interventions must navigate the complex socio-ecological systems in which food systems are embedded.

Based on the 1996 World Food Summit, food security is commonly understood through the lens of four primary pillars: availability, access, regularity, and utilization (FAO, 2015). These pillars encapsulate a wide array of interconnected issues, spanning from trade dynamics and market structures to considerations of nutrition, dietary patterns, and cultural preferences. Recent discourse, as articulated by De Raymond and Goulet (2020), has delineated two notable framings of food security: 'Global Food Security' and 'Food Sustainability'. Over the past decades, international institutions such as the FAO and World Bank have advocated for global food security through doubling down on production (Tomlinson, 2013). This emphasises the role of technological research and development in enhancing production efficiency, while simultaneously preserving the environment. However, food sustainability advocates focus on food sovereignty and a transition away from multinational agro-supply chains and intensive monoculture farming practices. prioritizing diverse and sustainable agricultural systems that are inclusive and equitable (Borras et al., 2018; Iles & De Witt, 2018)

The concept of Global Food Security traditionally emphasizes the equilibrium between food supply and demand, particularly in the face of escalating global population and rising incomes. This framing often advocates for agricultural productivity to meet rising demand, a perspective frequently endorsed by international institutions such as the FAO and World Bank. Slogans such as 'doubling production to feed the world in 2050' (Tomlinson, 2013) epitomize this approach, which underscores the role of technological research and development in enhancing production efficiency while simultaneously preserving the environment. However, critics argue that this perspective is outdated, characterised by neoproductivist and neoMalthusian ideologies, and reminiscent of the Green Revolution (Raymond and Goulet, 2020; Soil Association 20210; McKeon; 2018). In contrast, the Food Sustainability perspective shifts the focal point towards addressing food demand as the primary concern. It draws attention to the rise of Westernized diets and its impacts on public health and environmental sustainability. Rather than solely advocating for increased production, proponents of this approach advocate for transformative shifts in dietary habits, advocating for reduced consumption of processed foods, fats, sugars, and animal proteins. Moreover, they advocate for a transition away from multinational agro-supply chains and intensive monoculture farming practices, which primarily cater to cheap food demands in the Global North. Instead, they argue for redirecting efforts towards achieving food sovereignty and justice for all, prioritizing diverse and sustainable agricultural systems that are inclusive and equitable (Borras et al., 2018; Raymond and Goulet, 2020; Iles & De Witt, 2018).

Despite the opposing views, it would be beneficial to integrate elements from both perspectives to address the complex challenges facing global food security. While advancements in technology can play a role in increasing productivity it is important to acknowledge its limitations and unintended consequences which can be associated with intensive agricultural practices (Zscheischler et al., 2022; Barret & Rose, 2020). It is also important to understand how to move to self-sufficient systems that prioritize ecological health, community empowerment, social justice and the promotion of small-scale farming practices. In the context of Ethiopia, it is important to be mindful of both perspectives when navigating food security and potential pathways forward.

2.2 Climate Smart Agriculture

To facilitate this shift to a more sustainable and robust agricultural system, development institutions have promoted **'Climate Smart Agriculture' (CSA)** (Arakelyan et al. 2017). The concept of CSA rests on three pillars, namely; increasing productivity; improving resilience and adaptive capacity of farming systems and mitigate the effects of climate change (FAO, 2013; Rosenstock et al. 2016; Williams et al. 2015; Makate, 2019). Figure 1 below demonstrates how these concepts overlap to form climate smart agriculture. Furthermore, Steenwerth et al. (2014) expand this definition to include the provision of food security, poverty reduction and contributing to economic development and negotiating trade-offs between pillars in meeting such goals. Examples of CSA include, integrated crop, agroforestry, aquaculture and livestock systems, improved grassland and forestry management such as reduced tillage and the use of diverse crop varieties, restoring degraded lands, improving the efficiency of water, enhancing soil quality and carbon sequestration (Mwongera et al. 2017). A number of CSA practices and cases have been proven successful improving food security, productivity and incomes. For example, adopting stress adapted crop varieties, diversifying farming systems, the use of conservation farming and agroforestry (Makate, 2019).

Figure 1. Climate Smart Agriculture: Adaptation, Mitigation & Food Production

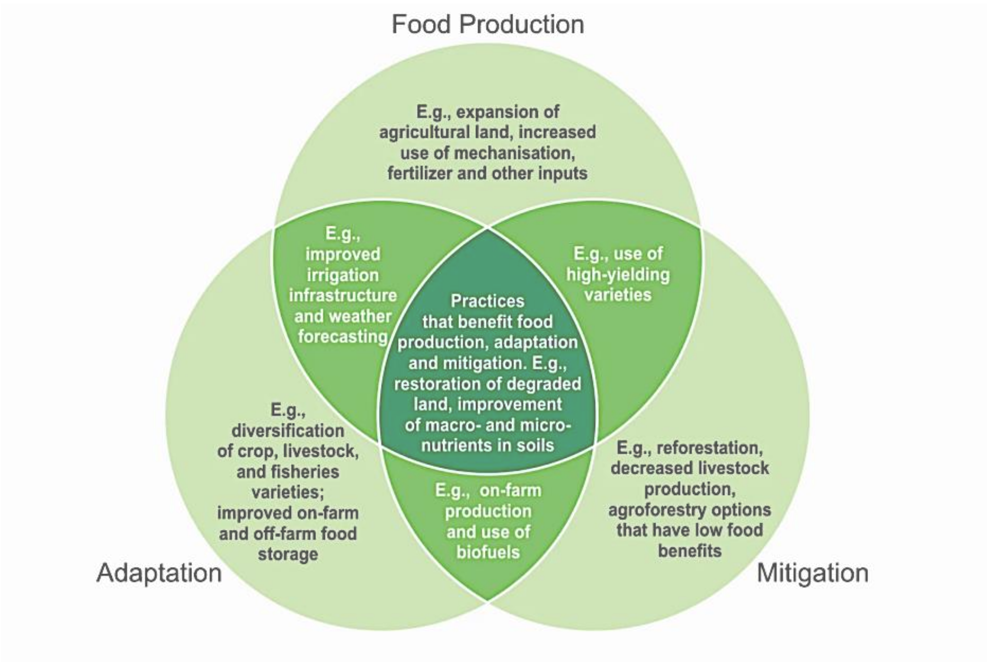


Image sourced from: Poudel, 2014

There is no set of novel agricultural practices that encompass CSA per se, but rather depends on the local climatic, biophysical, socio-economic and development context (Williams et al.

2015). In general, CSA solutions integrate technologies, services and traditional methods that are suitable to a specific location (Khatri-Chhetri et al., 2017). It encompasses both high tech and low tech solutions. As previously mentioned this paper defines high tech approaches to include precision agriculture, modified crops, climate modelling and digital services such as e-extension, market and weather information. Whereas low-tech approaches include sustainable land use techniques such as conservation tillage, agroforestry, residue management, intercropping, crop rotation, water storage and incorporating traditional knowledge. These solutions are commonly bundled together depending on the given context, and suitable solutions can change over time. As Rosenstock et al. (2016: 11) aptly points out "what is CSA in a location today may not be CSA in the same location in 20 years". Rather than promoting a one-size-fits-all technological solution, CSA uses an integrated approach which aims to improve social and environmental conditions despite the impacts of climate change, and mitigating climate change where possible (Rosenstock et al. 2016). Lipper et al., (2014: 1068), contends that "CSA differs from 'business-as-usual' approaches by emphasizing the capacity to implement flexible, context-specific solutions, supported by innovative policy and financing actions." As such, CSA is the process of identifying the most suitable strategies to suit local needs and priorities according to the social-cultural and environmental conditions that meet the CSA pillars (Williams et al. 2015).

CSA is often seen as a 'triple-win', which means it delivers on multiple development fronts; productivity, resilience and mitigation. For instance, Metz et al. (2007) highlights that increasing soil organic matter not only increases water holding capacity and soil fertility which can improve adaptive capacity and productivity but also mitigates climate change by sequestering carbon. This is a simple but effective triple-win intervention. However, securing a triple-win is not necessary for something to be considered CSA. More so, it is about identifying the opportunities and trade-offs between pillars and formulating effective responses in light of these considerations (Makate, 2019). CSA is highly context-specific, and so are the prioritization of the three pillars. For example, in resource poor smallholder farming systems, productivity and adaptive capacity can be prioritized over climate mitigation, though co-benefits should be integrated where possible.

However, CSA has faced some criticism in the literature. The CGIAR report on 'The scientific basis of climate-smart agriculture' sums up the concerns in the following paragraph.

> "*Simply put, a lack of criteria and boundaries leaves CSA open to interpretation, leading to concerns such as the CSA agenda merely 'greenwashing' corporate interests. But the concerns are not only the result of a vague definition. Initial discussions were perceived to concentrate too heavily on climate change mitigation and climate finance, leaving some to suspect that the true aim of CSA was to trap smallholders in complex carbon contracts. These issues, amongst others, have splintered the development community and raised questions about the added value of CSA"* (Rosenstock et al. 2016: 11).

Furthermore, Azadi et al. (2021) contend that CSA and does not adequately focus on the smallholder farmer and vulnerable populations that it should aim to support, proposing a shift to Vulnerable Smart Agriculture (VSA), which places the most vulnerable in the centre of the agricultural transformation. Similarly, Taylor et al. (2018) suggests replacing CSA with 'climate wise' agriculture which better accounts for the political and historical context and power dynamics on the local scale. Climate wise agriculture, aims to address power, access and inequality within the agricultural system while accusing CSA of 'occupying an apolitical terrain of providing technical solutions to natural problems' (Taylor, 2018: 8).

2.3 Implementation of Climate Smart Agriculture

Despite concerns, the approach has gained significant attention and has been integrated into the global development agenda by various governments and NGOs over the past decade. However, uptake has been rather limited for smallholder farmers, which means that scaling CSA faces significant problems. Furthermore, Makate et al. (2019) highlight that famers preferences are highly influenced by the cost of technologies and the likelihood of immediate benefits. For example, the uptake among technologies that address immediate concerns such as declining yields, stock feed shortages and pests have much greater chance of success (Douthwaite et al., 2007; Millar and Connell, 2010; Ojiem et al., 2006). Preferred CSA interventions in the study were crop-insurance, weather agro-advisory, rainwater harvesting site-specific integrated nutrient management contingent crop planning and laser land levelling (Makate et al. 2019).

Socio-cultural influences also weigh heavily on the success of interventions as well as community engagement, government resources and policies to support the scaling of CSA (; Millar and Connell, 2010; World Bank et al., 2003). Makate et al. (2019) state that successful scaling of CSA will need direct and immediate benefits of the technologies, peer learning and an iterative process, support from stakeholders, access to markets, credit, land and information, as well as a favourable political environment. Moreover, formal and informal institutions, human behaviour and affordable inputs such as fertilizer, seeds and equipment play a large role in successful implementation. Furthermore, while many focus on the national level providing a top-down approach there are methods and tools that integrate a participatory bottom up approach to CSA which can improve uptake (Mwongera et al. 2017). For example, the 'Climate Smart Agriculture Rapid Appraisal' which combines quantitative and qualitative tools to prioritize CSA in local areas (ibid). This can be used to understand priorities and trade-offs to inform investments. Thus, in engaging actors from the bottom up, accounting for power dynamics and centring vulnerable groups and smallholder farmers, it is possible to address the concerns about CSA and move toward inclusive agricultural development which are also location-specific and climate smart. As efforts to implement CSA gain traction, it becomes increasingly apparent that successful integration of these practices requires a comprehensive understanding of the intricate socio-technical-ecological dynamics at play within agricultural systems.

2.4 Agriculture as a Socio-Technical- Ecological System (STES)

Socio-ecological systems (SES) represent a dynamic interplay between human societies and the natural environment, embodying a complex web of interactions and feedback loops that shape both social and ecological outcomes. Within SES, the social component encompasses a diverse array of actors, including individuals, communities, institutions, and cultural norms, as well as economic activities and structures. The ecological component comprises the biodiversity of wild species and the intricate ecosystems they inhabit (Ahlborg, et al. 2019). They are nested, multilevel systems with feedback loops between social and ecological entities which can make outcomes highly dependent on one another and hard to predict (ibid). Within this framework, 'adaptive governance' emerges as a primary management strategy for socio-ecological systems. Adaptive governance refers to a range of actors, organizations, institutions and networks which work together to pursue a desired state of SES. In governing SESs from a resilience perspective the aim is not to limit changes but 'managing and shaping the ability of a system to cope with, adapt to, and allow for further change' (Chaffin et al., 2014; 56). It steers away from highly centralised, top-down and command-and-control policies in pursuit of collaboration from the local to the global, from bottom up to top-down with varying levels of flexibility to ensure its resilience.

Agricultural systems are part of a socio-ecological system which is reliant on both human and ecological interactions to ensure food security, livelihoods and healthy ecosystems. The social component includes, the farmers, their communities, governance, supply chains and social and cultural practices related to farming. The ecological component is the land and soil, the crop, the climate and environmental processes. If unsustainable agricultural practices or adverse events disrupt the soil, water and climate this can affect not only productivity of the land but also the health of the entire ecosystem. This can have profound impacts on both the social and ecological spheres, such as income loss, food insecurity and land degradation. Thus, adaptive governance in the agricultural sector involves multilevel decision-making from the local to the national to effectively manage and ensure resilience to shocks. For example, community-based natural resource management (CBNRM) which empowers local communities to collectively manage and steward their natural resources. Through collaborative decision-making, CBNRM initiatives promote sustainable land use practices, biodiversity conservation, and the equitable distribution of benefits, thereby fostering resilience in the face of environmental challenges (Dressler et al. 2010).

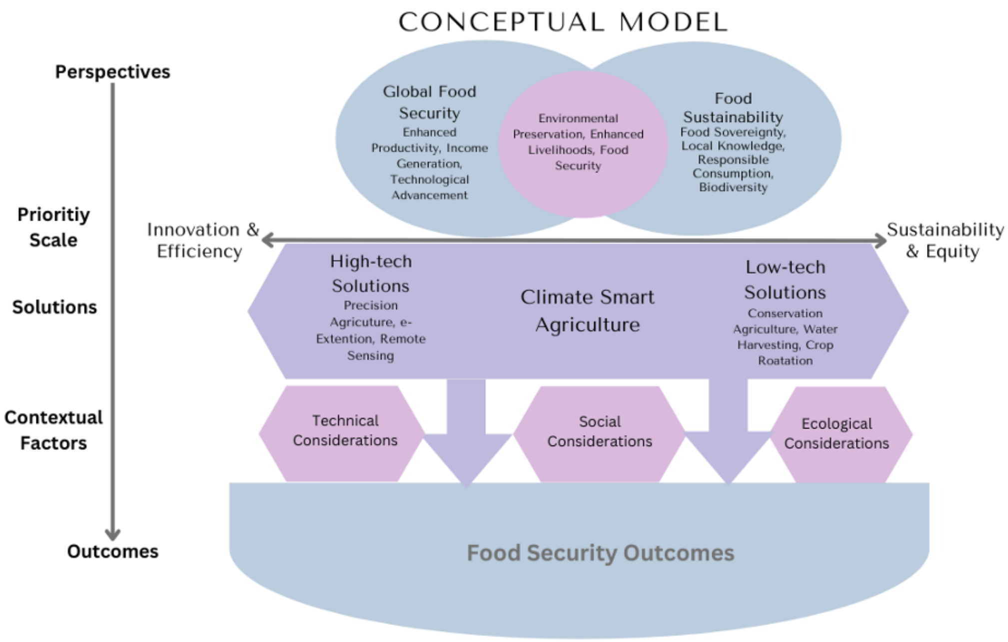
More recently, scholars have been keen to integrate technology into socio-ecological systems (SES) (Ahlborg et al. 2019; Smith and Stirling, 2008). Ahlborg et al. (2019) suggests pulling out technology in SES could be more analytically fruitful given the distinctive mediative nature of technology in human-nature relationships. This has been coined as 'Socio-technical-ecological systems (STES)'. Ahlborg et al. (ibid: 1) argues four reasons why technology is central to understanding SES as it; '(1) mediates human–environment relationships; (2) brings ambivalence to these relationships; (3) enhances and transforms human agency and provides a source of constitutive power; (4) changes scalar relationships, enabling our interaction with and impact on the natural world across time and space'. STES places technology as an enabler to maximise human capacity in the everyday lives of people, and sees potential for people to participate in the design and use of technology. This means ensuring that technology is clean and efficient but also democratic (ibid).

Furthermore, there are three areas of research for STES to address "1) how technologies shape specific human–nature relations and with what consequences, for whom, and where; 2) how emergent pressures in complex socio-technical-ecological systems are interlinked and; 3) how intentional and unintentional technical mediation may result in ambiguous outcomes and feedbacks that shatter the illusion of transcendence" (Ahlborg et al., 2019: 12). This paper will focus on the first area of research; how technologies shape specific human–nature relations and with what consequences, for whom, and where. It investigates the socio-technical-ecological implications of CSA methods in Ethiopia, by examining how CSA interventions can be designed in a way that empowers smallholders and vulnerable communities through high and low tech approaches. By delving into these complexities, the research endeavors to uncover synergies between different technological approaches to build a more resilient and sustainable agricultural future in Ethiopia and other developing countries.

2.5 Conceptual Model

The conceptual model below illustrates key concepts within the framework and demonstrates their interconnectedness. At the top of the model are the perspectives of Global Food Security and Food Sustainability, each accompanied by their respective values. In the middle layer, shared values such as environmental preservation, enhanced livelihoods, and food security are depicted. These perspectives inform priorities, resulting in a scale that ranges from innovation and efficiency to sustainability and equity. Within this scale, Climate-Smart Agriculture aligns differently: high-tech solutions lean towards innovation and efficiency, while low-tech solutions prioritize sustainability and equity. These alignments are crucial as they influence which solutions are seen as appropriate. Further, these solutions interact with the contextual factors —socio-technological and ecological— that shape their effectiveness and impact on food security outcomes. This research focuses particularly on the contextual factors to identify effective and sustainable solutions to enhance food security in Ethiopia.

Figure 2. Conceptual Model



(Created by Author)

3 Methodology

The methodology section of this research outlines the approach taken to gather and analyse the data in relation to the incorporation of high and low tech CSA solutions in Ethiopia. The research employs both a quantitative spatial analysis to create a vulnerability map of Ethiopia's regions as well as a qualitative survey informed by expert opinion. It aims to provide a comprehensive understanding of the socio-technical-ecological implications of CSA methods and their potential to empower smallholders in the country. While the map demarcates geographical focal points for tailored CSA strategies, qualitative analysis uncovers invaluable insights into the socioecological implications of CSA practices, emphasizing the importance of integrating high-tech and low-tech solutions.

Climate vulnerability maps have become essential tools for conveying the risks associated with climate change to society. These vulnerability maps serve the purpose of focusing attention on geographic regions where the societal impacts of climate change are anticipated to be most severe, thereby highlighting areas that may necessitate adaptation intervention (Sherbinin et al., 2019). These maps often combine a range of factors including, health, social, livelihood, economic and ecological impacts, but the use of indicators depend on the focus of the research. The majority of approaches frame vulnerability by considering adaptive capacity, sensitivity, and exposure when constructing these maps. Although vulnerability maps vary in spatial scales, they should align with the decision-making processes for which they are intended to be useful. As such, climate vulnerability maps will be increasingly important to understand human and climatic factors which will shape future impacts and inform decision-making (Sherbinin et al., 2019). The vulnerability maps used in this research focus on farmers adaptive capacity in terms of the digital readiness and support structures in agriculture and exposure to food insecurity. This is due to the current shifts in agriculture production in Ethiopia, as well as the current exposure to food insecurity risk in the country.

Furthermore, the qualitative surveys explore CSA through the perspective of experts. Qualitative surveys consist of a series of open-ended questions in which participants must answer the questions in their own words, without predetermined answers. It is an underutilized method, with qualitative research often dominated by interviews. Braun et al. (2021) suggests that the limited methodological discussion and utilization of qualitative surveys is due to the assumption that the data will lack depth. However, qualitative surveys can produce rich and complex account of the topic of interest even if individual responses are brief (ibid). Despite concerns around the depth of data, Bruan and Clarke (2013) found qualitative surveys to be densely packed with relevant information. This is in contrast to the sometimes extraneous details of an interview transcript. The length of the survey is an important consideration especially in qualitative surveys as not to risk participant disengagement or fatigue. Therefore, qualitative surveys often consist of 4-6 questions (Barrett, 2007; Frith & Gleeson, 2004, 2008; Clarke, 2016) with sample sizes anywhere between 20 to over 500 responses (Braun et al., 2021).

There were multiple reasons for choosing qualitative surveys for this research. Qualitative surveys give time and space for reflection and can provide succinct and well thought through answers. They provide a ‘wide-angle lens’ from a multitude of perspectives (Toerien and Wilkinson, 2004). Further, qualitative surveys are affordable, easy to distribute, with flexibility for participants to complete in their own time (Braun et al. 2021). Thus, given the research goals and timeframe, gaining a wide angle lens from multiple perspectives in a efficient and concise manner was important and therefore this method was deemed to be highly suitable.

3.1 Data Collection

Data Collection: Vulnerability Maps

To construct the vulnerability map the research utilized data from the Living Standards Measurement Study (LSMS) to uncovered dimensions such as digital readiness, social and technical agricultural supports in regions in Ethiopia. The LSMS is a detailed survey conducted in eight countries in Sub-Saharan by the World Bank in partnership with national statistics offices. Recognizing that this region suffers from inconsistent investment, institutional and sectoral isolation, and methodological weakness, the LSMS aims to gather information on multi-topic, nationally representative panel household surveys. It has a strong focus on agriculture, with the objective to support research on the links between agriculture and poverty reduction in the region. In Ethiopia, the survey is known as the Ethiopia Socioeconomic Survey (ESS), it has a focus on household welfare and income-generating activities. The ESS is implemented every two years, with 2018/2019 starting as a new panel and serves as a baseline survey for the next ESS waves (The World Bank, n.d.).

Additionally, the latest data from the Famine Early Warning Systems Network (FEWS-NET) was used in the research to estimate food security status in each region of Ethiopia. The FEWS NET is a leading provider of early warning and analysis on acute food insecurity around the world. The FEWS NET analysis assesses the degree to which households can meet basic survival needs and maintain normal livelihoods. It does this by closely monitoring a range of complex drivers such as climate, conflict, markets and trade. For example, staple food prices, household income, rainfall, crop production, and more. Then, to describe the current and anticipated level of food insecurity FEWS NET use the five-phase Integrated Food Security Phase Classification (IPC) (FEWS-NET, n.d.). The Integrated Food Security Phase Classification (IPC) is a widely accepted and multi-partner classification system and analytical approach to understanding food security and nutrition status and support decision-making. IPC phases are used to map the most likely acute food insecurity outcomes for near-term and medium-term (4 and 8 months into the future, respectively) projection periods. It is used by Governments, UN Agencies and NGOs to determine the severity and magnitude of food insecurity in a country, according to internationally-recognised scientific standards. This provides decision-makers with information to guide responses in the medium-and long-term policy and programming (IPC, 2024).

Data Collection: Qualitative Survey

Purposive sampling was used to target specific individuals who could provide the most insight into CSA in Ethiopia. This approach enhances the quality and accuracy of the data collected by selecting experts who are most relevant to the research question and ensuring diversity in professional backgrounds and unique perspectives. The criteria was to be:

1. From, worked in **or** published an article on Ethiopia
2. **and** working on **or** have worked on an CSA-related topic.

Participants were found through searching on Ethiopia's university websites, using Google Scholar to find relevant papers and contacting the authors, as well as through international organisations such as CGIAR and the Global Centre on Adaptation. The majority of experts contacted were from Ethiopia but also included many other nationalities such as the Dutch, Australian, Kenyan and British experts were also asked to participate. A diverse range of experts, including agronomists, environmental scientists, agricultural economists, geographers, social scientists and representatives from non-governmental organizations (NGOs), were contacted to participate in the survey. The qualitative survey was distributed online to 140 individuals, resulting in a 16.4% response rate, with 23 participants.

3.2 Analysis

Vulnerability Maps

Spatial analysis techniques were employed to enhance comprehension of the Ethiopian context within the research framework and provide a geographic perspective. Indicators from the Living Standards Measurement Study (LSMS) survey conducted in 2018/2019 and latest data from the Famine Early Warning Systems Network (FEWS-NET) formed the basis for compiling comprehensive data relevant to climate-smart agriculture. These indicators covered dimensions such as digital readiness, agricultural support systems, and food security projections. First, indices of digital readiness and agricultural support were compiled from the LSMS data (see Table 1; this does not include food security as this was not taken from the LSMS to form part of the index). Next, the latest FEWS-NET food security projections (May to September 2023) were incorporated to gauge food security status in the country. The most recent projection was used and altered to zonal level (one below regional), to give insight into challenges and adaptation measures that can be taken now by the local government.

Table 1. *Digital Readiness & Agricultural Support Index.*

Digital Readiness	TV Radio Telephone Mobile Phone Ownership Heard of Money Transfer Used Online Banking Used Mobile Banking Used Mobile to Pay a Bill Heard of Mobile Money Agents Enough Airtime to Initiate a Call
Agricultural Support	Presence of PSPN Improved Seeds Advisory Services Extension Agent Living in Community Watershed Activities Cooperative for Work Participation in Extension

The index assessed digital readiness by using binary data, such as whether households used mobile banking or owned a phone. Similarly, it evaluated agricultural support based on factors like the use of advisory services, improved seeds, or the presence of an extension agent in the community (table 1). Each indicator in the survey was answered yes or no, which were assigned 1 or 0 values. Scores for digital readiness and agricultural support were added according to each indicator, scoring a range of 0-10 (digital readiness) or 0-7 (agricultural support) (no to all or yes to all) in each household. These scores were then averaged at the zonal level. The FEWS-NET scoring ranged from 1-5 with from famine to minimal, this was brought from ward level (up by one administrative level) to the zonal level. This was done by spatially merging the borders and taking the average value of that region.

Following this, the spatial analysis involved a rigorous statistical technique known as K-means multivariate cluster analysis to create a vulnerability map for Ethiopia. It searched for similar profiles within the data, with different combinations of food security, agricultural support and digital readiness ratings. For example, high food security, moderate digital readiness and moderate agricultural support or low in all three. This facilitated the identification of distinct clusters characterized by similar profiles providing valuable insights for tailoring CSA strategies to specific contexts within Ethiopia. Using this technique enhances objectivity of manual categorisation and instead it automatically minimises differences within clusters and maximising differences between clusters. This resulted in four distinct clusters of low, medium, high and critical priority considering their digital readiness, agricultural support and food security profile (see appendix 1 for detailed information). It provides an assessment of the current agricultural landscape in Ethiopia in relation to CSA and valuable insights for tailoring adaptation strategies to specific sociotechnical contexts within Ethiopia. The analysis facilitated the identification of different focal points for climate-smart agriculture, for example, focusing on digital strategies such as e-extension versus building digital capacity, safety-nets and community-based methods.

Qualitative Survey

The expert qualitative surveys were conducted to gather insights into the socioecological implications associated with climate-smart agricultural practices. The questions aimed to explore the impact of climate-smart agriculture in Ethiopia and how both high-tech and low-tech solutions can be combined for sustainable farming as well as potential challenges and markers of success. Through this method, the rich and diverse responses provided by the experts were thoroughly examined to extract valuable insights. The qualitative surveys had a particular focus on the integration of high-tech and low-tech solutions and consisted of four open-ended questions:

1. What specific climate-smart agricultural strategies or interventions, encompassing both high-tech and low-tech approaches, do you envision as crucial for sustainable and resilient agricultural practices in developing countries like Ethiopia?;
2. Considering diverse social and ecological conditions, when do you believe it is most appropriate to prioritize high-tech solutions over low-tech solutions and vice versa?
3. In the context of climate-smart agriculture in Ethiopia, what potential social/cultural and ecological challenges might arise, and how can these be effectively navigated?
4. How can the effectiveness of climate-smart agriculture programs be measured beyond agricultural productivity metrics, what are the key indicators or markers of success from a socioecological perspective?

Thematic analysis was employed to systematically analyse the qualitative survey data, allowing for the identification of key themes, patterns, and insights. Using Atlas.TI the answers were coded inductively (into over 40 codes), and sorted by question into folders, namely, balancing high- and low-tech solutions; challenges and strategies to address challenges; essential CSA solutions and measurements of success. For example, in 'balancing high- and low-tech solutions' codes arose such as accessibility and inputs; affordability and perceived value; investment needs, technical resources and timeframe, context specificity and multiscalar and multi-stakeholder engagement.

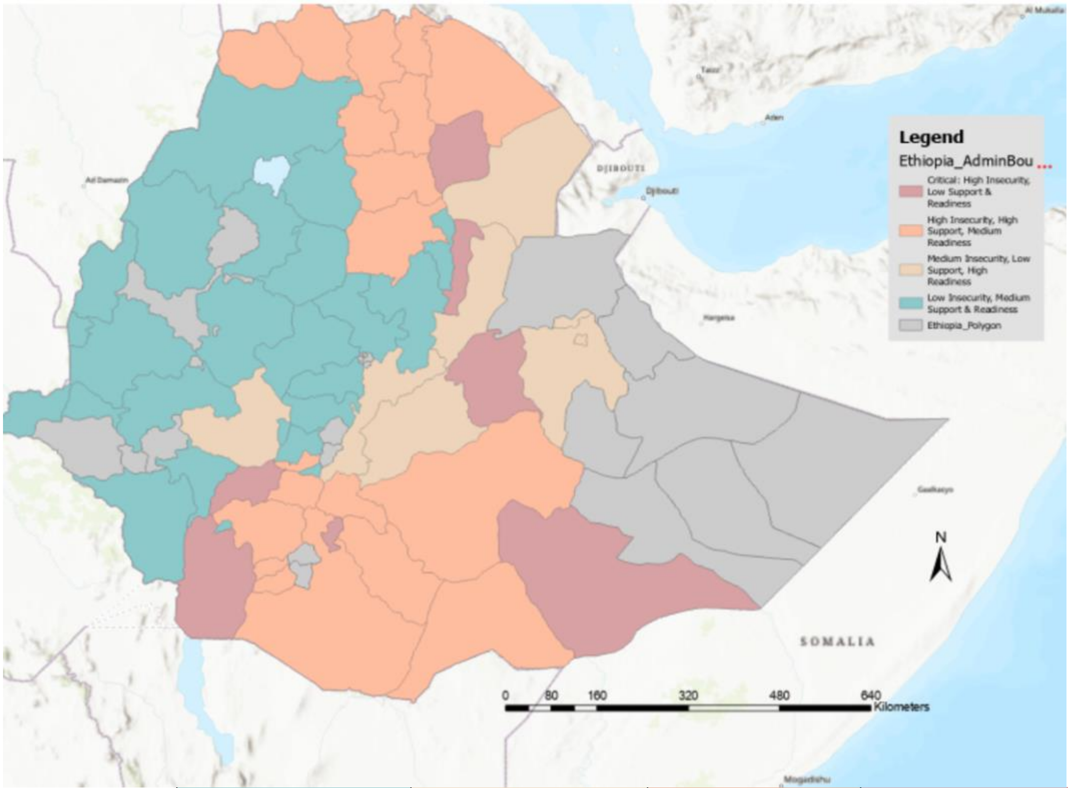
By blending qualitative insights from expert opinions with quantitative analysis of sociotechnical indicators the study provides a holistic understanding of navigating climate-smart agriculture in Ethiopia. While spatial analysis serves as geographical demarcations and focal points for tailored adaptation strategies in CSA, the qualitative analysis unearthed invaluable insights into the socio-technical and ecological implications of climate-smart agricultural practices, highlighting the crucial role of integrating high-tech and low-tech solutions.

4 Results: Conditions for Climate Smart Agriculture in Ethiopia

4.1 Mapping Digital Readiness, Food Security and Agricultural Support

As stakeholders navigate the multifaceted challenges of climate-smart agriculture in Ethiopia, a comprehensive understanding of location-specific obstacles is imperative. These challenges encompass digital illiteracy and limited access to agricultural support systems, which are crucial for enhancing food security and promoting sustainable practices. Understanding the distribution of digital readiness, food security, and agricultural support across diverse zones within Ethiopia sheds light on the varying levels of readiness and support available to farmers. By identifying priority areas and aligning interventions with local contexts, stakeholders can better address challenges and leverage opportunities in promoting climate-smart agriculture. This approach underscores the need to integrate both high-tech and low-tech solutions, ensuring their effectiveness and sustainability amidst socio-economic realities. The map below (fig.2) highlights the distribution of digital readiness, food security, and agricultural support across different zones in Ethiopia, providing insights for targeted interventions and strategic planning. Digital readiness and agricultural support vary widely across the country.

Figure 3. Digital Readiness, Food Security and Agricultural Support Map



Priority	Low	Medium	High	Critical
Colour	Green	Beige	Orange	Red
Area	Western Ethiopia	Northeast and Central Ethiopia	North and South	Scattered, close to areas of high priority
Food Security	High	Moderate	Low	Low
Digital Readiness	Moderate	High	Moderate	Low
Agricultural Supports	Moderate	Low	High	Low
Intervention Focus	Strengthening digital literacy & agricultural support, enhancing digital technology and NbS	Strengthen agricultural support, Digital approaches may be appropriate here, e-extension services, precision agriculture	Strengthening the existing digital literacy, enhancing digital technology and NbS	Focus on community-based adaptation and safety-nets, NbS early warning and digital literacy

The map has four clusters, each has ranked by priority of food security status, readiness and supports falling into low, medium, high and critical priority areas. The low priority zones are to the wsestern part of Ethiopia and typically, rank high in food security and have moderate digital readiness and agricultural supports available. These zones would benefit most by strengthening the existing digital literacy and existing agricultural support as well as enhancing digital technology available in these zones. The medium priority zones are mainly to the northeast and central parts of the country. Food security is moderate, digital readiness is high and they tend to have low levels of agricultural support. It would be beneficial to implement digital approaches in these zones as digital literacy is relatively high and introduce more agricultural supports. The orange cluster is of high priority due to the low level of food security in these zones. Although they score low on food security, typically, these zones rank moderately in digital readiness and highly on the agricultural supports and this is what distinguishes them from the critical category. These zones would benefit most by strengthening the existing digital literacy, enhancing digital technology. The red cluster is of critical priority. They are scattered throughout the country but generally remain close to areas of high priority. These zones generally score low in food security, digital readiness and agricultural support. Therefore, it would be most appropriate to focus on more community-based approaches and safety-nets, Nature based solutions (NbS), early warning and digital literacy.

4.2 Balancing High- and Low-Tech Solutions

In the discourse on essential strategies for climate-smart agriculture in Ethiopia, participants advocated for a diverse array of solutions, spanning both low-tech and high-tech approaches. Emphasizing the importance of resilience and sustainability, low-tech and nature-based solutions featured prominently. Participants mentioned integrated soil and water management techniques, such as water harvesting, small scale irrigation, mulching, intercropping, cover cropping, crop rotation and residue incorporation, as well as rangeland management. Furthermore, the importance of climate resilient seeds and new varieties featured heavily. Meanwhile, high-tech solutions focused predominantly on digital climate advisory services, precision agriculture, and climate modeling, aimed at providing timely information and enhancing agricultural productivity.

Many participants highlighted an integrated approach that combines both high- and low-tech solutions. They emphasized working with nature through practices like agroforestry and conservation agriculture, alongside conserving water as a foundational strategy. Additionally, they proposed enhancing these methods with advanced technologies such as precision farming techniques, real-time weather information, and genetically modified seeds. This highlighted by the participants in the following responses:

> *"Key climate-smart agricultural strategies crucial for sustainable and resilient practices in developing countries like Ethiopia include adopting drought-resistant crop varieties, implementing water-efficient irrigation methods, promoting agroforestry to enhance biodiversity and soil health, and integrating precision farming technologies for efficient resource use. These strategies, encompassing both high-tech and low-tech approaches, aim to mitigate climate risks and enhance the overall resilience of agricultural systems"* (Participant 12)

> "*Develop and promote the use of genetically modified or traditional crop varieties that are resistant to pests, diseases, and extreme weather conditions. Implement Information and Communication Technology (ICT) solutions, such as mobile apps, to provide farmers with real-time weather updates, market information, and best agricultural practices. Employ satellite imagery and remote sensing technologies to monitor crop health, assess soil moisture, and predict weather patterns. Agroforestry, Water Harvesting Techniques, Conservation Agriculture, Water Management Systems,*

Capacity Building and Education Drought-Resistant Farming Techniques, Community-Based Adaptation Programs” (Participant 18)

Participants stressed the necessity of simplicity, affordability, and community-driven initiatives, cautioning against overreliance on external expertise or monoculture practices. They highlighted the importance of context-specific, low-tech interventions for enhancing agricultural resilience. They noted that in regions with a rich tradition of local knowledge and limited resources, simpler, low-tech solutions that fit well with existing practices are often more effective and sustainable than advanced technologies. This approach ensures that interventions are practical, affordable, and culturally appropriate, leveraging local expertise and resources. By prioritising low-tech strategies tailored to the local context, communities can address their specific challenges more effectively and build greater resilience against climate change. This focus underscores the need to align agricultural solutions with the realities on the ground, ensuring that they are both feasible and impactful. Of the participants emphasized the importance of context-specific interventions and integration of low-tech approaches:

> *“[It] depends on the problem and the impact intended from the climate smart agricultural technology. The technology itself has to have direct impact to the people, sustainable in terms of cost and simple for all to understand and implement. This could include integrated watershed management, integrated soil fertility management, sustainable land management, conservation agriculture, agroforestry, crop residue management, composting, promotion of improved livestock feed and rangeland management”* (Participant 17).

> *“I think that it would be contextually more appropriate to focus on low-tech climate-smart agricultural practices (e.g. various water conservation measures, contours to reduce soil-erosion on slopes, various agro-ecological cropping practices). This builds up the expertise of the farmers and reduces their dependency on technicians and companies selling the technologies (and service contracts), thus ensuring a reduced cash flow (esp. since farmers tend to have limited cash available)”* (Participant 19).

When deliberating on the prioritization between low-tech and high-tech solutions, participants emphasized several crucial factors. It was highlighted that low-tech approaches are best suited for areas characterized by low technological literacy and an unskilled workforce, as well as for small-scale community-based projects with limited infrastructure and conservative attitudes. Moreover, in resource-constrained settings where affordability, accessibility are paramount, low-tech solutions emerge as the preferred choice, particularly for smallholders seeking long-term sustainability. The sentiment prevails that low-tech options still harbour untapped potential.

Conversely, high-tech solutions find their niche in environments boasting ample access to resources, technological literacy, and a skilled workforce, particularly within commercial farms and agribusinesses. However, cautionary notes were sounded against adoption of high-tech interventions, especially in settings lacking the requisite infrastructure or economic capacity to sustain such technologies, underscoring the importance of aligning technological solutions with prevailing socio-economic conditions for optimal impact. Furthermore, collaboration with the community and economic assessments were deemed essential for prioritization, while tasks were recommended to be clearly shared among various stakeholders, including government, institutions, and NGOs, with accountability mechanisms in place. This is demonstrated in the responses below:

> "*The prioritization between high-tech and low-tech solutions should be context-dependent. High-tech solutions are suitable for well-established infrastructure and advanced economies, providing precision and efficiency. In contrast, low-tech solutions are more appropriate in resource-constrained settings, promoting affordability, accessibility, and adaptability. A balanced approach, considering the specific social and ecological conditions of each context, is essential for effective and sustainable solutions*" (Participant 12).

> *"High tech is great in places where existing infrastructure allows it. High tech interventions in places where the space available, production amounts, and infrastructure are not sufficient to provide a good return on investment shouldn't be subsidized--at some point those high tech solutions are no longer subsidized and will soon be forgotten. Low tech, culturally appropriate solutions seem critical on the small scale and in places where infrastructure (internet, phone, roads, etc) are limited/dated/unavailable"* (Participant 7).

4.3 Challenges, Strategies and Measurements of Success

In navigating the multifaceted challenges of climate-smart agriculture (CSA) in Ethiopia, it is imperative to grasp the nuances of location-specific obstacles. The participants cited a great number of prominent barriers to the adoption of CSA. This included access and funding to climate smart agriculture technologies, climate change and environmental concerns as well as diversity in landscapes, digital illiteracy, inequity between genders and entrenched resistance to changing traditions. Additionally, participants mentioned fragmented land holdings, migration of the youth and intergenerational transfer of agricultural knowledge, institutional challenges, pest and disease management and political turmoil as challenges to incorporating CSA practices. The quotes below highlight some of the challenges Ethiopia faces in terms of CSA adoption:

> *"There are location specific challenges throughout Ethiopia. The general ones include: digital illiteracy, lack of agroecosystem specific technologies, fragmented and small land holdings, resistance to changing the traditions"* (Participant 1).

> *"Resistance to change from traditional farming practices. A strategy to navigate this is by building local capacity, through community engagement programs to raise awareness about the benefits of climate-smart practices, emphasizing their compatibility with local knowledge. Another challenge is unequal access to resources and decision-making power between men and women. For this it is important to implement gender-sensitive climate-smart interventions, ensuring that both men and women have equal access to training, resources, and participation in decision-making processes."* (Participant 5)

Effective adaptation strategies must address the distinct challenges encountered in social, ecological, and technological realms. Socially, overcoming resistance to change and ensuring community engagement through awareness programs that integrate indigenous knowledge and promote gender sensitivity are crucial. Ecologically, adapting to challenges such as drought and varying conditions between lowlands and highlands requires targeted solutions. Technologically, addressing barriers like limited access to advanced technologies, low smartphone penetration rates, and risk aversion among farmers is essential. Bridging skill and capacity gaps is particularly important when introducing high-tech solutions. Additionally, political instability highlights the need for resilience-focused approaches. Tackling these multifaceted challenges is key to developing effective adaptation strategies that are both practical and impactful

Measuring the success of climate-smart agriculture (CSA) initiatives encompasses a broad spectrum of indicators that extend beyond agricultural productivity metrics. The participants named a wide range of metrics that could be used to measure the success of interventions. Enhancing adaptive capacity and resilience, improving income profitability and livelihoods, ensuring food security and nutrition, and promoting household welfare and satisfaction emerged as key indicators. Additionally, other vital indicators mentioned were educational attainment, empowerment and social inclusion, resource use efficiency and climate mitigation.

> *“Beyond agricultural productivity metrics, the effectiveness of climate-smart agriculture programs can be measured by key socioecological indicators. These may include improvements in farmers' adaptive capacity, increased resilience to climate extremes, enhanced biodiversity and soil health, reduced environmental impact, and the empowerment of local communities. Assessing changes in these indicators provide a holistic view of the program's success in promoting sustainable and resilient agricultural practices”* (Participant 11).

> *“(..) Assessing the effectiveness of climate-smart agriculture (CSA) programs from a socio-ecological perspective involves examining a range of indicators that go beyond agricultural productivity such as Social Equity and Inclusivity, Community Resilience, Climate Mitigation and Adaptation, Livelihood Diversification, Food Security and Nutrition, Knowledge Transfer and Capacity Building, Indigenous Knowledge and Cultural Values etc.”* (Participant 17).

Overall, a comprehensive evaluation framework is essential for understanding the holistic impact of CSA initiatives.

5 Discussion

In exploring readiness for high and low-tech CSA solutions to enhance food security in Ethiopia, socio-technical-ecological systems (STES) serve as a framework for understanding the interplay between human societies, technology, and the environment. By integrating the STES framework, the analysis interprets agricultural systems not merely as ecological processes but also deeply intertwined with contextual social and technological dynamics. CSA directly enhances food security by implementing practices that make food systems more resilient to climate shocks and stresses, thereby ensuring stable food supplies and improving the livelihoods of farming communities. In Ethiopia, where food insecurity is a pressing issue, CSA practices offer a pathway to improve agricultural productivity while also addressing climate vulnerabilities. However, employing the right solutions is critical to the success of these measures. The technology implemented in Ethiopia will play a pivotal role in mediating the human-nature relationships, agricultural, food security and livelihood outcomes. For example, the integration of climate information services, digital advisory, and modeling tools can enhance resilience and productivity. However, this brings about complexities, and high-tech solutions must be carefully implemented to avoid unintended consequences and ensure equitable outcomes. For instance, while digital tools may provide valuable information to farmers, they can also exacerbate existing disparities in access to resources and information, particularly among marginalized communities.

The vulnerability map highlights the differentiated needs across the country. Targeted interventions and strategic planning can address challenges and leverage opportunities for promoting CSA, which will directly impact food security. Digital literacy varies across the country. High-tech solutions are more appropriate in some areas, whereas nature-based and traditional methods will be better suited to others. The four clusters identified strategic entry points such as focusing on strengthening digital literacy, agricultural supports, or investing in community-based initiatives in particular locations. However, this assessment is only a stepping-stone in identifying appropriate context-specific solutions. It can only give an indication of the capacity and risk in areas, illustrating the diverse needs across the country. Spatial analysis cannot be used as a substitute for on-the-groundwork with local communities. Therefore, the map serves as more of an introductory informational resource, which can be further enhanced through community consultation.

Experts contributed to a wider discussion on the socio-technical-ecological implications of CSA. Participants highlighted various methods for advancing CSA, including enhancing digital literacy, strengthening agricultural support systems, and integrating nature-based solutions. While acknowledging the potential benefits of high-tech solutions, there was caution against overreliance on external expertise or monoculture practices. In line with Makate et al. (2019), the cost and perceived benefits were cited as key factors in the uptake of CSA, with access and funding seen as prominent barriers. Socio-cultural influences such as entrenched resistance to changing traditions and gender inequity were also identified as inhibitors. Participants stressed the necessity of simplicity, affordability, and community-driven initiatives. In the context of using CSA for enhancing food security, these considerations echo the sentiments emphasized by Raymond and Goulet (2020) regarding food sustainability and sovereignty. This aligns with the literature's emphasis on promoting diverse and sustainable agricultural systems that prioritize inclusivity and equity (Azadi et al. 2021; Taylor et al., 2018).

Despite emphasizing low-tech, nature-based solutions, participants thought it possible to integrate some high-tech approaches to complement these where suitable. Such as improving weather and market information through digital technology, and modified seeds. This juxtaposition highlights a willingness among experts to adopt a multidimensional approach considering the social, ecological, and technical dimensions of food production and security. Enhancing digital literacy and information access aligns with the Government's ‘Digital Ethiopia Strategy 2025’ plans, supporting smallholders in becoming more resilient to climate change. Nevertheless, further considerations of self-sufficiency, sovereignty, and food sustainability could improve existing agricultural strategies.

In the context of improving food security through the use of high- and low-tech CSA, capitalizing on increased production through high-tech CSA solutions aligns with the 'Global Food Security' perspective. However, empowering smallholders benefits from further reflection on 'Food Sustainability' (Raymond and Goulet, 2020). Bridging these perspectives can address challenges in agri-food systems. While technological progress enhances productivity, it's crucial to recognize its constraints and unintended repercussions, particularly regarding intensive agricultural methods. Equally important is transitioning towards self-sustaining systems that prioritize ecological well-being, community empowerment, social equity, and advancing small-scale farming approaches. This paper advocates for moving away from binary thinking when implementing CSA, arguing against the necessity of exclusively supporting either high-tech or low-tech solutions, ecological or technical approaches, or prioritizing global food security over food sustainability perspectives. Instead, it emphasizes recognizing the benefits of both approaches and utilizing them where they are most suitable.

Moreover, the integration of STES approaches prompts us to critically examine the trade-offs inherent in agricultural development strategies. While high-tech solutions may offer productivity gains, they may also contribute to environmental degradation and social inequalities if not implemented carefully. Therefore, it is imperative to adopt an approach that balances technological innovation with ecological integrity and social equity. Adaptive governance emerges as a key strategy for navigating the complexities of STES in CSA interventions. By embracing adaptive governance, stakeholders can collaboratively navigate the complex socio-technical-ecological landscape of CSA in Ethiopia. This entails engaging local communities in decision-making processes, fostering knowledge exchange among diverse actors, and promoting flexible governance structures that can respond to changing environmental conditions. Aligning technological advancements with the needs of smallholders and the environment can foster a more resilient and sustainable agricultural future with that, enhancing food security in Ethiopia. By embracing STES principles through adaptive governance, Ethiopia can support the development of robust and contextually relevant agricultural interventions that promote sustainability, resilience, and equity in place-based CSA. A reorientation from economic productivity to prioritizing healthy and prosperous people and planet necessitates measurements of success outside of productivity. The results emphasized the importance of measuring the success of agricultural initiatives beyond agricultural productivity metrics, encompassing indicators such as biodiversity conservation, resilience, and overall well-being.

6. Conclusion

This study sheds light on the landscape of food security, digital readiness, and agricultural support in Ethiopia, emphasizing the diverse needs across the country. The spatial analysis underscores the importance of targeted interventions and strategic planning to address challenges and capitalize on opportunities for promoting CSA and in turn, enhancing food security. While recognizing the potential benefits of both high-tech and low-tech solutions, it's imperative to root interventions in local contexts and socio-technical-ecological realities.

The insights from experts echo a call for a multidimensional approach to CSA, acknowledging the significance of simplicity, affordability, and community-driven initiatives, complemented by few high-tech solutions – such as improved access to information – where appropriate. Moreover, barriers to CSA adoption such as cost, access, and socio-cultural influences, highlight the need for adaptive governance and participatory bottom-up approaches. Moving forward, collaboration, flexibility, and community consultation will be essential in laying the groundwork for place-based CSA initiatives. Low-tech approaches should serve as the foundation, complemented by improved digital literacy and access to information, aligning with national digital development agendas. However, further reflection on self-sufficiency, sovereignty, and food sustainability is warranted to enhance current plans and bridge perspectives between global food security and food sustainability. Ultimately, this study advocates for a shift from solely prioritizing economic productivity to considering broader metrics of success such as biodiversity conservation, resilience, and overall well-being. By embracing a holistic evaluation framework, agricultural initiatives can better serve the needs of both smallholders and the environment, paving the way for a more sustainable and equitable food system in Ethiopia and beyond.

Reference List

African Development Bank. (2019). *Feed Africa*. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Brochure_Feed_Africa_-En.pdf

Agricultural Transformation Agency. (2021). *Annual Report*. ATA. https://www.ata.gov.et/

Ahlborg, H., Ruiz-Mercado, I., Molander, S., & Masera, O. (2019). Bringing technology into social-ecological systems research—Motivations for a socio-technical-ecological systems approach. *Sustainability, 11*(7), 2009. https://doi.org/10.3390/su11072009

Arakelyan, I., Moran, D., & Wreford, A. (2017). Climate smart agriculture: A critical review. In *Making climate compatible development happen* (pp. 66-86). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315621579-4/climate-smart-agriculture-irina-arakelyan-dominic-moran-anita-wreford

Asrat, D., & Anteneh, A. (2020). Status of food insecurity in dryland areas of Ethiopia: A review. *Cogent Food & Agriculture, 6*(1), 1853868. https://doi.org/10.1080/23311932.2020.1853868

Azadi, H., Movahhed Moghaddam, S., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *Journal of Cleaner Production, 319*, 128602. https://doi.org/10.1016/j.jclepro.2021.128602

Barrett, C. B., Benton, T., Fanzo, J., Herrero, M., Nelson, R. J., Bageant, E., ... & Wood, S. (2022). Socio-technical innovation bundles for agri-food systems transformation. *Springer International Publishing*. https://doi.org/10.1007/978-3-030-88802-2

Barrett, H., & Rose, D. C. (2022). Perceptions of the fourth agricultural revolution: What's in, what's out, and what consequences are anticipated?. *Sociologia Ruralis, 62*(2), 162-189. https://doi.org/10.1111/soru.12324

Barrett, J. (2007). 'You've made mistress very, very angry': Displeasure and pleasure in media representations of BDSM. *Particip@tions, 4*(1). http://www.participations.org/Volume%204/Issue%201/4_01_barrett.htm

Bilali, H. E., Hauser, M., Wurzinger, M., Melcher, A., & Probst, L. (2018). Power and politics in agri-food sustainability transitions. https://ifsa.boku.ac.at/cms/fileadmin/Proceeding2018/Theme5_ElBilali.pdf

Borras, S. M., Franco, J. C., & Suárez, S. M. (2018). Land and food sovereignty. In *Food sovereignty* (pp. 170-187). Routledge. https://doi.org/10.4324/9781315227580-10

Braun, V., & Clarke, V. (2013). *Successful qualitative research: A practical guide for beginners*. Sage. https://www.researchgate.net/publication/256089360_Successful_Qualitative_Research_A_Practical_Guide_for_Beginners

Braun, V., Clarke, V., Boulton, E., Davey, L., & McEvoy, C. (2021). The online survey as a qualitative research tool. *International Journal of Social Research Methodology, 24*(6), 641–654. https://doi.org/10.1080/13645579.2020.1805550

Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: synthesis and future directions. *Ecology and Society, 19*(3). http://www.jstor.org/stable/26269646

Chamberlin, J., Jayne, T. S., & Headey, D. (2014). Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy, 48*, 51-65. https://doi.org/10.1016/j.foodpol.2014.06.004

Clarke, V. (2016). Wearing a gay slogan t-shirt in the higher education classroom: A cautionary tale. *Feminism & Psychology, 26*(1), 3–10. https://doi.org/10.1177/0959353515613812

Clarke, V. (2019). "Some university lecturers wear gay pride T-shirts. Get over it!": Denials of homophobia and the reproduction of heteronormativity in responses to a gay-themed T-shirt. *Journal of Homosexuality, 66*(5), 690–714. https://doi.org/10.1080/00918369.2017.1423217

Conti, C., Zanello, G., & Hall, A. (2021). Why are agri-food systems resistant to new directions of change? A systematic review. *Global Food Security, 31*, 100576. https://doi.org/10.1016/j.gfs.2021.100576

De Raymond, A. B., & Goulet, F. (2020). Science, technology and food security: An introduction. *Science, Technology and Society, 25*(1), 7–18. https://doi.org/10.1177/0971721819889916

Deininger, K., & Byerlee, D. (2011). *Rising global interest in farmland: Can it yield sustainable and equitable benefits?* World Bank Publications. https://documents1.worldbank.org/curated/en/998581468184149953/pdf/594630PUB0ID1810Box358282B01PUBLIC1.pdf

De Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., ... & Zhang, S. (2019). Climate vulnerability mapping: A systematic review and future prospects. *Wiley Interdisciplinary Reviews: Climate Change, 10*(5). https://doi.org/10.1002/wcc.600

Douthwaite, B., Schulz, S., Olanrewaju, A. S., & Ellis-Jones, J. (2007). Impact pathway evaluation of an integrated *Striga hermonthica* control project in Northern Nigeria. *Agricultural Systems, 92*(1-3), 201-222. https://doi.org/10.1016/j.agsy.2006.03.007

Dressler, W., Büscher, B., Schoon, M., Brockington, D., Hayes, T., Kull, C. A., ... & Shrestha, K. (2010). From hope to crisis and back again? A critical history of the global CBNRM narrative. *Environmental Conservation, 37*(1), 5-15. https://doi.org/10.1017/S0376892910000315

FAO. (2013). *Climate-smart agriculture sourcebook*. https://www.fao.org/4/i3325e/i3325e.pdf

FAO. (2015). *Climate change and food security: Risks and responses*. https://openknowledge.fao.org/server/api/core/bitstreams/a4fd8ac5-4582-4a66-91b0-55abf642a400/content

FAOSTAT. (2021). *Analytical brief 53 employment indicators 2000–2021*. https://www.fao.org/faostat/en/#data

FEWS NET. (n.d.). Famine Early Warning Systems Network. https://fews.net/

Frith, H., & Gleeson, K. (2004). Clothing and embodiment: Men managing body image and appearance. *Psychology of Men & Masculinity, 5*(1), 40–48. https://doi.org/10.1037/1524-9220.5.1.40

Frith, H., & Gleeson, K. (2008). Dressing the body: The role of clothing in sustaining body pride and managing body distress. *Qualitative Research in Psychology, 5*(4), 249–264. https://doi.org/10.1080/14780880701752950

Gladek, E., Fraser, M., Roemers, G., Sabag Munoz, O., Hirsch, P., & Kennedy, E. (2016). *The global food system: An analysis*. Amsterdam: METABOLIC. https://www.metabolic.nl/publications/global-food-system-an-analysis-pdf/

Hertel, T. W. (2011). The global supply and demand for agricultural land in 2050: A perfect storm in the making?. *American Journal of Agricultural Economics, 93*(2), 259-275. https://doi.org/10.1093/ajae/aaq107

Iles, A., & De Wit, M. M. (2018). Sovereignty at what scale? An inquiry into multiple dimensions of food sovereignty. In *The politics of food sovereignty* (pp. 61-76). Routledge. https://doi.org/10.4324/9781315226156-5

Jayne, T. S., & Sanchez, P. A. (2021). Agricultural productivity must improve in sub-Saharan Africa. *Science, 372*(6546), 1045-1047. https://doi.org/10.1126/science.abf5413

Khatri-Chhetri, A., Aggarwal, P. K., Joshi, P. K., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural Systems, 151*, 184–191. https://doi.org/10.1016/j.agsy.2016.10.005

Lambin, E. F., Gibbs, H. K., Ferreira, L., Grau, R., Mayaux, P., Meyfroidt, P., ... & Munger, J. (2013). Estimating the world's potentially available cropland using a bottom-up approach. *Global Environmental Change, 23*(5), 892-901. https://doi.org/10.1016/j.gloenvcha.2013.05.005

Li, G., & Wang, W. (2016). *Investing in Africa's agriculture: Solidifying foundation for sustainable and inclusive development*. The World Bank. https://documents1.worldbank.org/curated/en/847331472710963734/pdf/108109-REVISED-WP-PUBLIC.pdf

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., ... & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change, 4*(12), 1068–1072. https://doi.org/10.1038/nclimate2437

Makate, C. (2019). Effective scaling of climate-smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. *Environmental Science & Policy, 96*, 37-51. https://doi.org/10.1016/j.envsci.2019.01.014

McKeon, N. (2018). Are equity and sustainability a likely outcome when foxes and chickens share the same coop? Critiquing the concept of multistakeholder governance of food security. In *The politics of destination in the 2030 sustainable development goals* (pp. 45-63). Routledge. https://doi.org/10.4324/9780429490507-3

Metz, B., Davidson, O. R., Bosch, P. R., Dave, R., & Meyer, L. A. (2007). *Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press. https://archive.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

Millar, J., & Connell, J. (2010). Strategies for scaling out impacts from agricultural systems change: The case of forages and livestock production in Laos. *Agriculture and Human Values, 27*(2), 213-225. https://doi.org/10.1007/s10460-009-9194-9

Modi, R. (2019). The role of agriculture for food security and poverty reduction in sub-Saharan Africa. In *The Palgrave handbook of contemporary international political economy* (pp. 391-410). https://doi.org/10.1057/978-1-137-45443-0_25

Mohamed, A. A. (2017). Food security situation in Ethiopia: A review study. *International Journal of Health Economics and Policy, 2*(3), 86-96. https://doi.org/10.11648/j.hep.20170203.11

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., ... & Winowiecki, L. A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural Systems, 151*, 192–203. https://doi.org/10.1016/j.agsy.2016.05.009

Ocho, F. L., Yadessa, G. B., Abdissa, F. M., & Bekele, A. E. (2017). Why does food insecurity persist in Ethiopia? Trends, challenges and prospects of food security in Ethiopia. *Journal of Development and Agricultural Economics, 9*(12), 341-354. https://doi.org/10.5897/JDAE2017.0846

OECD & FAO. (2016). *OECD-FAO Agricultural Outlook 2016-2025*. OECD Publishing. https://doi.org/10.1787/agr_outlook-2016-en

Ojiem, J. O., De Ridder, N., Vanlauwe, B., & Giller, K. E. (2006). Socio-ecological niche: A conceptual framework for integration of legumes in smallholder farming systems. *International Journal of Agricultural Sustainability, 4*(1), 79-93. https://doi.org/10.1080/14735903.2006.9686011

Peng, Y., Hirwa, H., Zhang, Q., Wang, G., & Li, F. (2021). Dryland food security in Ethiopia: Current status, opportunities, and a roadmap for the future. *Sustainability, 13*(11), 6503. https://doi.org/10.3390/su13116503

Plaizier, W. (2016, January 22). 2 truths about Africa's agriculture. *World Economic Forum*. https://www.weforum.org/agenda/2016/01/2-truths-about-africa-s-agriculture

Poudel, S. (2014, December 21). Climate-smart agriculture: A development alternative. *Sanjok Poudel's Blog*. https://sanjokpoudel.wordpress.com/2014/12/21/climate-smart-agriculture-a-development-alternative/

Rosenstock, T. S., Lamanna, C., Chesterman, S., Bell, P., Arslan, A., Richards, M. B., ... & Zhou, W. (2016). The scientific basis of climate-smart agriculture: A systematic review protocol. *CCAFS Working Paper*. https://hdl.handle.net/10568/70967

Scherr, S. J., & McNeely, J. A. (2008). Biodiversity conservation and agricultural sustainability: Towards a new paradigm of 'ecoagriculture' landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences, 363*(1491), 477-494. https://doi.org/10.1098/rstb.2007.2165

Smith, A., & Stirling, A. (2008). Social-ecological resilience and socio-technical transitions: Critical issues for sustainability governance. https://doi.org/10.1080/14735903.2006.9686011

Soil Association. (2010). *Telling porkies: The big fat lie of doubling down on production*. Soil Association. https://www.soilassociation.org/media/4906/policy_telling_porkies.pdf

Steenwerth, K. L., Hodson, A. K., Bloom, A. J., Carter, M. R., Cattaneo, A., Chartres, C. J., ... & Jackson, L. E. (2014). Climate-smart agriculture global research agenda: Scientific basis for action. *Agriculture & Food Security, 3*(1), 11. https://doi.org/10.1186/2048-7010-3-11

Tamene, L. D., & Ashenafi, A. (2022). *Digital agriculture profile: Ethiopia*. https://cgspace.cgiar.org/handle/10568/119309

Taylor, M. (2018). Climate-smart agriculture: What is it good for? *The Journal of Peasant Studies, 45*(1), 89–107. https://doi.org/10.1080/03066150.2017.1312355

The Federal Democratic Republic of Ethiopia. (2020). *Digital Ethiopia 2025 – A strategy for Ethiopia inclusive prosperity (Version 4.2)*. https://www.lawethiopia.com/images/Policy_documents/Digital-Ethiopia-2025-Strategy-english.pdf

The Ministry for Agriculture and Natural Resources. (2017). *Agricultural extension strategy of Ethiopia*. https://faolex.fao.org/docs/pdf/eth205099.pdf

The World Bank. (n.d.). *Ethiopia Socioeconomic Panel Survey - Wave 5*. https://microdata.worldbank.org/index.php/catalog/6161#:~:text=The%20Ethiopia%20Socioeconomic%20Panel%20Survey%20(ESPS)%20is%20a%20collaborative%20project,(LSMS%2DISA)%20team

The World Bank. (2020). *Climate risk profile: Ethiopia*. https://climateknowledgeportal.worldbank.org/sites/default/files/2020-06/15463-WB_Ethiopia%20Country%20Profile-WEB_v2.pdf

Toerien, M., & Wilkinson, S. (2004). Exploring the depilation norm: A qualitative questionnaire study of women's body hair removal. *Qualitative Research in Psychology, 1*(1), 69–92. https://doi.org/10.1191/1478088704qp006oa

Tomlinson, I. (2013). Doubling food production to feed the 9 billion: A critical perspective on a key discourse of food security in the UK. *Journal of Rural Studies, 29*, 81–90. https://doi.org/10.1016/j.jrurstud.2011.09.001

United Nations Environment Programme. (2024). *Our work in Africa*. https://www.unep.org/regions/africa/our-work-africa

Vermunt, D. A., Negro, S. O., Van Laerhoven, F. S. J., Verweij, P. A., & Hekkert, M. P. (2020). Sustainability transitions in the agri-food sector: How ecology affects transition dynamics. *Environmental Innovation and Societal Transitions, 36*, 236–249. https://doi.org/10.1016/j.eist.2020.06.003

Williams, T. O., Mul, M., Cofie, O., Kinyangi, J., Zougmore, R., Wamukoya, G., ... & Campbell, B. (2015). Climate-smart agriculture in the African context: An action plan for African agricultural transformation. *The African Development Bank*. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/DakAgri2015/Climate_Smart_Agriculture_in_the_African_Context.pdf

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., ... & Jonell, M. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet, 393*(10170), 447-492. https://doi.org/10.1016/S0140-6736(18)31788-4

World Bank. (2016). *CPIA Africa - Assessing Africa's Policies and Institutions: 2015 CPIA Results for Africa*. Washington, D.C.: World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/733581467039657221/assessing-africas-policies-and-institutions-2015-cpia-results-for-africa

World Wildlife Fund-UK. (2013). *A 2020 vision for the global food system. Report Summary*. http://assets.wwf.org.uk/downloads/2020vision_food_report_summary_feb2013.pdf

Zerssa, G., Feyssa, D., Kim, D. G., & Kassa, H. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture, 11*(3), 192. https://doi.org/10.3390/agriculture11030192

Zscheischler, J., Brunsch, R., Rogga, S., & Scholz, R. W. (2022). Perceived risks and vulnerabilities of employing digitalization and digital data in agriculture–Socially robust orientations from a transdisciplinary process. *Journal of Cleaner Production, 358*, 132034. https://doi.org/10.1016/j.jclepro.2022.132034