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Trends, Status and Challenges of Ethiopian Agricultural Sector in Achieving the Pillars of Climate-Smart Agriculture: A Synthesis Review

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ABSTRACT

The Ethiopian agricultural sector, which serves as the backbone of the country's economy and livelihoods, has been significantly impacted by climate variability and change. In this review, we have assessed the trends, challenges and some Climate- smart Agriculture (CSA) practices and technologies that could improve the usage of climate-smart agricultural practices. A combination of the adoption of climate-smart agricultural practices such as conservation agriculture, integrated soil fertility management, small scale irrigation, agroforestry, crop diversification and improved livestock feed and feeding practices are being used for specific purposes in Green-house Gas (GHG) emission mitigation and climate change adaptation. However, adoption of climate-smart agriculture technology is ineffective mainly due to the, low skills, knowledge and poor technical use of the technologies. The importance of conservation agriculture as a key climate-smart practice for Ethiopia has to be recognized among high-level policy-makers and decision-makers as well as government and civil society organizations in the country. In this line concerted efforts to continuously generate CSA technologies would contribute to the desired positive outcome. An aggressive awareness-creation program of conservation agriculture technology should be pursued at federal and regional level. The policies and implementation strategies should be emphasized on an integrated, evidence-based and climate smart approach for enhancing food security at all levels, from the national to local levels, from research to policies and investments, and across private, public and civil society sectors to achieve the scale and rate of change required.

Keywords: Climate change, climate smart agriculture, Ethiopia

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RÉSUMÉ
En raison de la variabilité et du changement climatiques, le secteur agricole éthiopien, pilier de l'économie nationale et des moyens de subsistance du pays, a été gravement affecté. Dans cette revue, nous avons évalué les tendances, les défis ainsi que certaines pratiques et technologies d'agriculture intelligente face au climat (CSA) susceptibles d'améliorer l'utilisation des pratiques agricoles intelligentes face au climat. Une combinaison de l'adoption de pratiques agricoles intelligentes telles que l'agriculture de conservation, la gestion intégrée de la fertilité des sols, l'irrigation à petite échelle, l'agroforesterie, la diversification des cultures et l'amélioration de l'alimentation du bétail est utilisée à des fins spécifiques pour atténuer les émissions de gaz à effet de serre (GES) et l'adaptation au changement climatique. Cependant, l'adoption des technologies de l'agriculture intelligente face au climat reste inefficace principalement en raison des faibles compétences, du manque de connaissances et de la mauvaise utilisation technique des technologies. L'importance de l'agriculture de conservation en tant que pratique clé de l'agriculture intelligente face au climat pour l'Éthiopie doit être reconnue parmi les décideurs de haut niveau ainsi que les organisations gouvernementales et de la société civile du pays. Dans ce cadre, des efforts concertés pour générer en continu des technologies CSA contribueraient au résultat positif souhaité. Un programme de sensibilisation intensif à la technologie de l'agriculture de conservation devrait être mené aux niveaux fédéral et régional. Les politiques et stratégies de mise en œuvre doivent mettre l'accent sur des approches intégrées, fondées sur des preuves et intelligentes face au climat pour renforcer la sécurité alimentaire à tous les niveaux, du national au local, de la recherche aux politiques et aux investissements, et dans les secteurs privé, public et de la société civile, afin d'atteindre l'échelle et le rythme de changement requis.

Mots clés: Changement climatique, agriculture climatiquement intelligente, Éthiopie

INTRODUCTION

World hunger and food insecurity have increased in recent years, after a continued decline over the last decades. Undernourishment is especially rising in sub-Saharan Africa, including Ethiopia (Yigezu, 2021) affecting an estimate of 23% of the population. Partly because of the rapid population growth in sub-Saharan Africa, the total number of undernourished people has increased by more than 22% within six years (FAO *et al.,* 2018). Current population trends for Africa predict a further doubling of the population by 2050 and there is therefore a crucial need to produce more food and improve food security and nutrition, especially for small producers (Jeremy *et al.,* 2021). Around 85% of Ethiopian people live in rural areas. Most rural households produce their own food, but, rather ironically, they are often more affected by food insecurity than their urban counterparts (Grebmer *et al.,* 2018, Teklewold *et al.*, 2019, Zeleke *et al.*, 2021). At the same time, climate change is predicted to complicate this aim, with models projecting temperature increases across sub-Saharan Africa, changes in rainfall patterns and increases in extreme events, such as heatwaves, droughts, and extreme rainfall events, although with varying confidence (FAO *et al.,* 2018). These future changes are likely to negatively affect agricultural production and increase the risk for further food insecurity. Particularly those households that are already food insecure, i.e., rural households and subsistence farming systems, will also be the most vulnerable in the future (Tura, 2016; Yodit et *al.,* 2019).

The agriculture sector is the backbone of Ethiopia's economy and livelihoods. Yet, heavy reliance on rain-fed systems has made the sector particularly vulnerable to variability in rainfall and temperature. Its contribution was 46.3% of the national GDP and 90% of foreign exchange earnings of the country (USAID. 2017). Due to climate change, national gross domestic product (GDP) may decrease by 8–10% by 2050, but adaptation action in agriculture could cut climate shock-related losses by half. Most of Ethiopian smallholder farmers have been experiencing poor yields, food insecurity and poverty due to extreme climatic events, climate variability and change (USAID. 2017; Adem *et al.,* 2018; Lemi and Hailu, 2019; Mahtsente *et al.,* 2021). Climate Smart Agriculture (CSA) has been proposed as an integrative approach to mitigate ongoing climate change and adapt to its consequences without compromising food security.

Cultivation practices are usually affected by climate change through the occurrence of extreme weather conditions such as rainfall variability, droughts, flash floods, and patterns, therefore causing shifts in the timing and length of growing seasons and differences in the prevalence and severity of pests, diseases and weeds (Ubisi, 2016; Alastair *et al.*, 2021). Although all farming systems might experience the effects of climate change, smallholder farmers are usually the most vulnerable due to their high dependence on climate-sensitive rain-fed agriculture. According to FAO (2016), most Ethiopian smallholder farmers have a low adaptive capacity and low resilience to deal with the impacts of extreme climatic events, high climate variability, and change.

A search of existing literature indicated that several factors are influencing the adoption of agricultural technology. In most of Sub-Saharan Africa including Ethiopia, agricultural practice is based on rainfed systems (Gebrehiwot and Gebrewahid, 2016; Eric, 2020; Andrew and Ryan, 2021; Jonne *et al.,* 2021). So far, the use of resources conserving technologies such as off-season Agriculture, integrated pest management, nutrient cycling, soil and water conservation, water harvesting and waste cycling are some of untouched by the modern technology. The adaptive capacity of communities and the responsiveness of institutions to facilitate actions in CSA need to be integrated into research and development. It is therefore important to have a proactive platform for governmental institutions, NGOs, donors, the private sector and civil society organizations in Ethiopia to fill gaps and enhance collective action on CSA. Thus, this review paper aimed to assess climate-smart agricultural (CSA) practices in Ethiopia, in achieving pillars of Climate-Smart Agriculture.

Trend in Ethiopian Agricultural Land Use

In Ethiopia, growing land scarcity is a serious problem; for such the present land tenure regulations are a major contributor. Farmers are only granted user rights, not ownership rights, under the current land tenure system, hence land cannot be sold, exchanged, or mortgaged. Farmers have very limited options for acquiring additional land (Gebre-Selassie and Bekele, 2012). However, an informal land market appears to have emerged recently. The issue of land shortage for food production and cultivation purpose could potentially lead to multiple constraints including an inability to meet food security, especially for the rural farm households. Not only shortage of sufficient food production, food loss, and food wastage are huge problems in the supply chain system (Tadele, 2021).

Agriculture in Ethiopia includes crops, livestock, forestry, fisheries, apiculture, and other natural resources. It is the most critical sector of the national economy and the primary source of livelihood for 85% of the population (FAO, 2016; Komarek *et al.*, 2018). However, the production and productivity of agriculture in the country are highly vulnerable to climate variability (Lemi and Hailu, 2019, Dendir and Simane, 2019, Ylva *et al.,* 2020, Mahtsente *et al.,* 2021). Climate variables such as temperature, reduced rainfall, and increased rainfall variability reduces crop yield and threaten food security in low-income and agriculture-based economies (Gezie, 2019; Geda and Kühl.2021). The effect of climate change is attributed to the reduction of crop yields and incomes, and the human health of the population engaged in agricultural production is generally expected to be adverse (Komarek *et al.,* 2019; Alastair *et al.*, 2021).

In Ethiopia, climate change-related health problems like mortality and morbidity due to floods and heatwaves, vector-borne diseases, water-borne diseases, meningitis, and air pollution-related respiratory diseases increase (Simane *et al.,* 2017; Tsige *et al.,* 2020). Climate change has caused recurrent droughts and famines, flooding, expansion of desertification, loss of wetlands, loss of biodiversity, and water shortage resulting in the decline of agricultural production (Zegeye, 2018; Tsige *et al.,* 2020). IPCC (2013) depicts that spatial and temporal distribution of water resources become uneven due to global climate change effects. Other evidence indicates that the major impact of climate change on Ethiopia's economy will result from the more frequent occurrence of extreme hydrologic events, which cause losses in both the agricultural and non-agricultural sectors. As a result, the patterns of climate change data show that rainfall is increasingly erratic with marked seasonal deficits when compared to long term past averages, droughts appear to be increasingly frequent, heavy rainfall events appear to be increasingly frequent, with changes in rainfall patterns, including decreased reliability and less predictability for agricultural activities (USAID, 2015; Komarek *et al.*, 2018).

Existing Farming Systems. The Government of Ethiopia has given top priority to the agricultural sector and has taken a number of steps to increase productivity (Table 1). Ethiopia has good indigenous knowledge on soil and water conservation and farming system (Birhanu *et al.*, 2021, Tarirai *et al.*, 2019), however strong dependence of the country on agriculture, which is very sensitive to climate variability and change, is a cause for concern. One of the key goals of COP26 is putting the policies in place that will enable the world as a whole to achieve net-zero. This means cutting our greenhouse gas emissions to a level where global warming will be kept under 1.5 degrees and as a result, we will retain a planet that is liveable for communities and nature (Barnes *et al.*, 2022). Ethiopia's annual greenhouse gas (GHG) emissions were estimated at 150 Mt CO2e in 2010, with 50 percent and 37 percent of these emissions resulting from the agricultural and forestry sectors respectively. In Ethiopia, about 60% of farmers cultivate less than 0.90 ha in very fragmented landscapes (Rapsomanikis, 2015). However, smallholder farming is responsible for a large proportion of Ethiopian food production. It cultivates more than 90% of the total cropland and provides more than 90% of agricultural output (Aweke and Gelaw, 2017, Yodit *et al.*, 2019). Crop yields in the smallholder farms are very low compared to their potential capacity (Taffesse *et al.*, 2013; Van Loon *et al.*, 2018; Fentie and Beyene, 2019) and are also substantially lower (less than 50%) than the yields obtained in experimental farms and research stations. **Land use.** Ethiopia's land area totals 1.1 million square kilometers (km^2). Agricultural area occupies around 35% of total land area. Through the Constitution, the State owns all rural land and farmers have land-use rights. There are approximately 17.5 million agricultural land holders in the country, occupying 18 million hectares of land. As land has been fragmented to satisfy the needs of new generations, most smallholder farms are between 0.5 and 2 hectares in size. The small plot sizes in the country are often insufficient to enable household food security or adequate income to invest in improved farming methods. Large, commercial farms (over 10 ha) are not widespread; extending over 1.2% of the total agricultural land area and contributing less than 5% of gross agricultural output (FAO, 2016).

In recent years, there has been an increased understanding that Governance of community-managed forests exhibits inadequacy in achieving positive livelihood outcomes. Policies and practices in several African countries paid little attention to governance aspects of community-managed forests (Magessa *et al.*, 2020). In Ethiopia, community-managed forests are governed under diverse institutional arrangements. The institutional context in turn influences the level of community participation, leadership responsibilities and commitments, and levels of public contributions to collective action (Yami and Mekuria, 2022). The decrease in vegetation cover and disturbance of the natural ecosystem have caused widespread of soil degradation, contributing to decline in soil organic matter (SOM) and nutrient stocks (Gelaw *et al.*, 2014; Eric, 2020; Ishmael *et al.*, 2022). In the lowlands and midlands, over 19 million ha of fertile and uncultivated land is estimated to be available for agricultural investments (FDRE. 2011).

There has been a steady increase in area under grain crops (cereals, pulses, oilseeds) over the past decades, from 10 million hectares in 2005/2006, to 12.4 million hectares in 2014/2015 (CSA, 2016). Agricultural expansion has been carried out at the expense of natural resources availability and quality (particularly forests, water and soils). For example, in the highlands, where most Ethiopians live, over 40% of the land area is said to be undergoing some form of soil erosion, causing topsoil losses of over 1,493 million t/year and affecting regional and national crop production (Molla and Sisheber, 2017). Unsustainable open grazing practices have also led to pasture degradation.

Table 1. Importance of smallholder farming systems in Ethiopia (FAO, 2016)

Farming system	Smallholder agriculture	Commercial agriculture
• Highland mixed agriculture • Lowland mixed agriculture • Highland mixed agriculture • Highland mixed agriculture	• 95% of the annual gross total agricultural output of the country • Average farm size ranging from 0.5 to 2 hectares	• 95% of the annual gross total agricultural output of the country

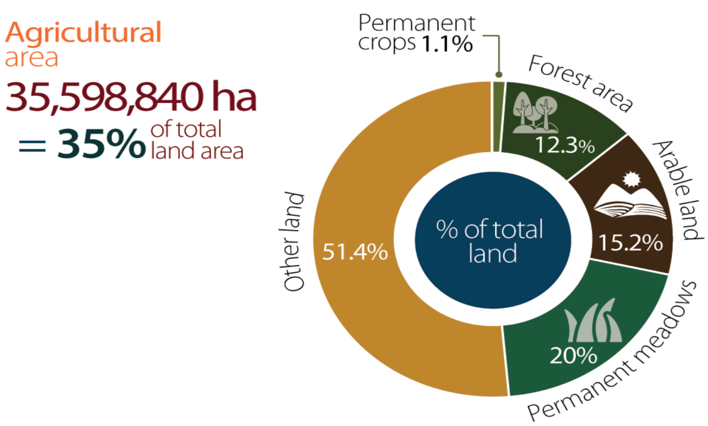

Figure 1. Ethiopian Land Use (USAID. 2017)

Climate smart agriculture (CSA) tiers of Government. There are five tiers of government in Ethiopia, each with different roles and duties with regards to agricultural policy making and implementation: the federal Government who make aim, and other who are implementing the aim or goal l are regions, zone administrations, woreda, and kebele. The Federal Government is responsible for the formulation and implementation of national policies, strategies and plans and also allocates the budget to the regions, depending on population size and capacity to contribute to national budget through revenues (Shikur, 2020). The Regional Councils are entitled to legislate and execute laws, but also to exercise judicial power. The regions design socio-economic development plans that meet national-level targets and are also able to generate their own revenue, although dependency on federal budget is still high (ODI, 2016; Shikur *et al.*, 2020). This illustrates a complex context not only for legislation and policy development, but also for budget allocation and management (Linus *et al.*, 2018).

In Ethiopia, lack of information, insufficient financial support, lapses encountered in farming practices puts farmers in situations where they need financial support to enable them grow, expand and improve their yields, access to better fertilizers, market access and transportation challenges (WFP, 2016; Hadgu, 2019; Zerssa *et al.*, 2021).

CSA practices and technologies implemented and adopted. Adoption levels of some CSA practices and technologies as part of livelihoods and food security improvement, a multitude of agricultural development activities are conducted in Ethiopia, both traditionally and innovatively for example by the initiation or national interest of Ethiopian government, wheat irrigation-based agriculture is currently actively practicing at farmer cluster across the country. Currently, agricultural development activities carried out in the country are supported by a number of policies, strategies and institutions. Of the numerous agricultural development activities conducted, mention should be made of those that are considered important in addressing issues related to climate change and are contributing to climate change adaptation and mitigation (Peter *et al.*, 2018; Sizwile *et al.*, 2021; Stéphane *et al.*, 2021). Such agricultural practices in Ethiopia 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, Irrigation water management (Cheik *et al.,* 2014; Beyene *et al.*, 2019; FAO, 2021; Jeremy *et al.* 2021; Mihiretu *et al.*, 2021).

Climate innovative agricultural (CSA) practices sustainably increase productivity, enhance resilience, remove GHGs, and enhance national food security and development goals (Seline *et al.,* 2015; FAO, 2018; Kifle *et al.,* 2021; UFCCC, 2021; Barnes *et al.,* 2022; Ishmael *et al.,* 2022). There are different climate-smart agricultural practices in Ethiopia (Table 2,). These practices consist of different components and are used for Specific purposes in GHG emission mitigation and climate change adaption (Table 2).

Major Pillars of Climate Smart Agriculture. Ambitious and explicit targets have been set to reach millions of agricultural households with CSA (FAO, 2018). Many interventions have been identified as potentially able to contribute toward pillars CSA, such as drought tolerant crops, integrated soil fertility management, water conservation techniques, better integration of livestock in smallholder mixed crop-livestock farms and land restoration in rangelands (FAO, 2018; Rosenstock *et al.*, 2019; Berhe *et al.*, 2020).

The framework to assess the current CSA assessment tools is based on CSA pillars like: food security, adaptation, and mitigation (Figure 2). In this section we explain this framework and the choices we made to be able to assess the individual tools in a balanced and comparable manner. We treat the individual pillars separately in the framework, even though we are aware that this can sometimes be rather artificial. According to Balehegn *et al.* (2020) and Francis *et al.* (2022) concept of sustainability has important consequences and nuances for both the food security and adaptation, while the environmental part of sustainability could further be covered under the mitigation pillar. However, we decided to proceed with the structure of using the separate pillars with the important notion, and this will be repeated throughout the text, that some issues/developments apply to multiple pillars. The Food and Agriculture Organization of the United Nations (FAO) defines climate-smart agriculture as consisting of three pillars (Figure 3): (1) sustainably increasing agricultural productivity and incomes (food security) (Geremew and Fatih. 2016) (2) adapting and building resilience to climate change (adaptation) (Jonne *et al.*, 2021; UFCCC, 2021; Francis *et al.*, 2022); and (3) reducing and/or removing greenhouse gas emissions (mitigation) (Peter *et al.,* 2019; Shiferaw, 2021; UFCCC, 2021), where possible.

Status of Climate-smart agricultural practices in Ethiopia. Highly fragmented land units are not suited for effective implementation of some CSA practices, while land tenure regimes can significantly hinder credit access for smallholders (Table 3). Ethiopia has made great effort to issue land certificates to smallholder farmers, and such programs should be accompanied by sensitization of farmers and microfinance providers on the costs and benefits of investing in on-farm climate-smart and sustainable land management practices. Through an ambitious policy framework built largely on the Climate Resilient Green Economy. Strategy and an enabling institutional infrastructure, Ethiopia has taken major steps towards mainstreaming climate change into agricultural planning (Komarek *et al.*, 2018; Berhe *et al.,* 2020; Diana *et al.* 2021). To demonstrate its unwavering commitments to green growth and food security and operationalize strategies and plans, additional national and international resources need to be mobilized over the next years, to fill existing financial gaps.

Table 2. Some Climate Smart Agriculture practices in Ethiopia (FAO, 2016).

CSA practice Components	Components	Why it is climate smart
Conservation agriculture	○ Reduced tillage ○ Crop residue management mulching, intercropping ○ Crop rotation/intercropping	○ Carbon sequestration ○ Reduce existing emissions ○ Resilience to dry and hot spells
Integrated soil fertility management	○ Compost and manure management, including green manuring ○ Efficient fertilizer application techniques (time and amount)	○ Reduced emission of nitrous oxide and CH4 ○ Improved soil productivity
Small-scale irrigation	○ Year-round cropping ○ Irrigation water use management	○ Creating carbon sink ○ Improved yields ○ Improved food security
Agroforestry	○ Tree-based conservation agriculture ○ Practiced both traditionally and as improved practice ○ Farmer-managed natural regeneration	○ Trees store large quantities of CO2 ○ Can support resilience and improved productivity of agriculture
Crop diversification	○ Popularization of new crops and crop varieties ○ Pest resistance, high yielding, tolerant to drought, short season	○ Ensuring food security ○ Resilience to weather variability ○ Alternative livelihoods and improved incomes
Improved livestock feed and feeding practices	○ Reduced open grazing/zero grazing ○ Forage development and rangeland management ○ Feed improvement ○ Livestock breed improvement and diversification	○ Improved livestock productivity ○ GHG reduction ○ CH4 reduction
Other	○ In situ water conservation ○ Early-warning systems and improved weather information ○ Support to alternative energy fuel efficient stoves, biofuels ○ Crop and livestock insurance ○ Livelihood's diversification (apiculture, aquaculture) ○ Post-harvest technologies (agro processing, storage)	○ Resilience of agriculture ○ Improved incomes ○ Reduced emissions ○ Reduced deforestation ○ Reduced climate risk

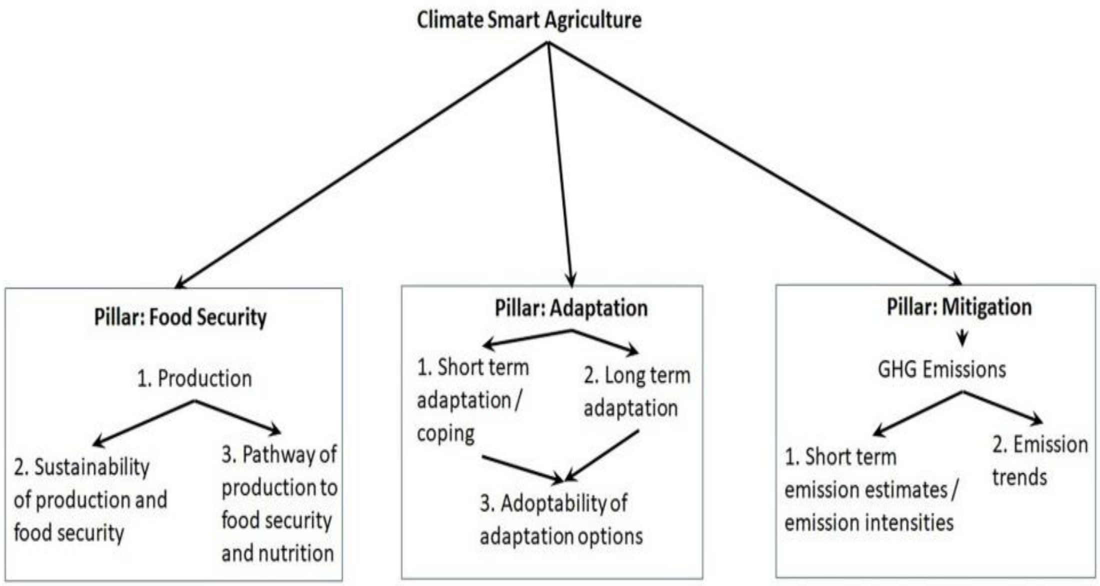

Figure 2. Scheme of the pillars of CSA (Vanwijk *et al.*, 2020)

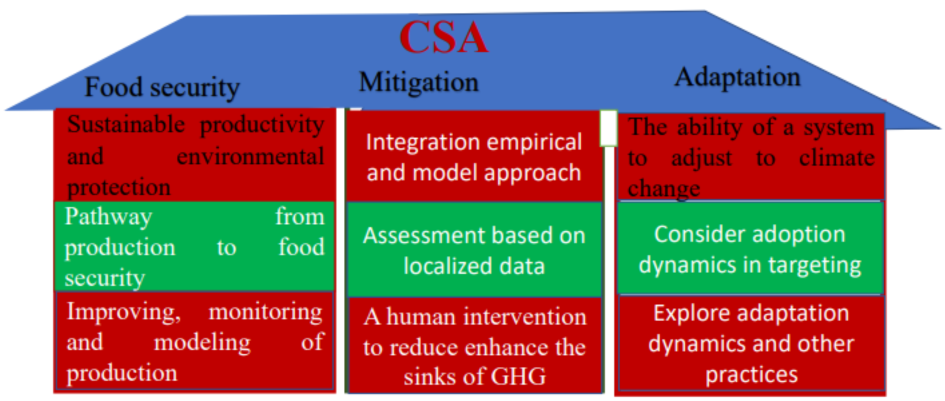

Figure 3. The pillars of CSA, (source: own modification from the reviewed paper).

Status of Climate-smart agricultural practices in Ethiopia. Highly fragmented land units are not suited for effective implementation of some CSA practices, while land tenure regimes can significantly hinder credit access for smallholders (Table 3). Ethiopia has made great effort to issue land certificates to smallholder farmers, and such programs should be accompanied by sensitization of farmers and microfinance providers on the costs and benefits of investing in on-farm climate-smart and sustainable land management practices. Through an ambitious policy framework built largely on the Climate Resilient Green Economy. Strategy and an enabling institutional infrastructure, Ethiopia has taken major steps towards mainstreaming climate change into agricultural planning (Komarek *et al.*, 2018; Berhe *et al.*, 2020; Diana *et al.* 2021). To demonstrate its unwavering commitments to green growth and food security and operationalize strategies and plans, additional national and international resources need to be mobilized over the next years, to fill existing financial gaps.

Small-scale irrigation practice in Ethiopia has embarked on the promotion and implementation of small-scale irrigation across the country. Irrigation and water availability increase biomass and contribute significantly to improved wheat yield and water productivity (Ehsan *et al.* 2021; Ibsa *et al.,* 2021; Oner and Cuma, 2021). The availability of irrigation infrastructure and sufficient water for crop and livestock production can also increase the number of cropping seasons and reduce the risks associated with rain-fed agriculture and the rearing of livestock in a drought-prone and water scarce country. This can have a significant impact on food security and climate change adaptation. Depending on national interest currently irrigated based agriculture like wheat-based irrigation that is started 2020 accurses the country need appropriate water management for efficient water utilization coupled with improved agronomic practices. There is a need to ensure that appropriate training on agronomy and water management is given along with support to develop irrigation use. In the absence of irrigation, many farmers have practiced different forms of rainwater harvesting, including in-field rainwater harvesting as well as more advanced practices such as roof rainwater harvesting. These techniques can support farmers to retain water for improved crop resilience to weather variability, particularly mid-season dry spells

Table 3. Production costs, productivity and profitability of producing major rain-fed and irrigated crops in Meskan, Sodo and Mareko woredas between 2017 and 2018, Ethiopia (GOE, 2007)

Crop type	Average harvest on 0.5 hectares of land (Quintals)	Production cost (Birr)	Average Market price per quintal (Birr)	Total price (Birr)	Net profit (Birr)
Rain-fed major crops					
Maize	30	4,218	500	15,000	10,782
Teff	9	4,000	1,500	13,000	9,500
Irrigation-fed vegetables					
Tomato	280	70,000	700	196,000	126,000
Onion	120	20,000	600	72,000	52,000

Agricultural production systems. Ethiopia's proximity to the equator and its wide range of altitudes reflects distinct climate and agro-ecological conditions that favor the production of a diversity of agricultural goods, while at the same time posing challenges for technology development and targeting, mechanization and agricultural input (e.g. fertilizer) recommendations (Beyene *et al.*, 2019; Kombat *et al.,* 2021). The most commonly used categorization of Ethiopia's agricultural production systems refers to five main agro-ecological zones, namely, moisture reliable cereal-based highlands (where the majority of the farmers live), moisture reliable enset-based highlands, drought-prone highlands, humid lowlands, and pastoralist areas (Figure 4).

Cereals such as barley, maize, sorghum, wheat, and teff extend over three quarters of the country's cultivated in moist land area and constitute the main source of food and income for the majority of smallholder farmers. Being a staple food for Ethiopians, teff accounts for 28% of the total cultivated area; it has traditionally been cultivated in the highlands, but it is quite adaptable to lower elevations and a variety of moisture, temperature and soil conditions. Maize is also grown by a large majority of farmers for food, fodder and sales; with its production volume being the highest among all crops. Sorghum and wheat each occupy around 17% of the grain-cultivated land. Sorghum has high tolerance to drought and high temperatures, but is less suitable for Ethiopia's high-altitude areas due to the cold temperatures, which are not favorable for the crop. Cultivated areas higher than 2,500 m.a.s.l. are almost exclusively dedicated to barley and wheat, which represent key components of the country's diet, and grown using many local varieties (Chamberlin and Schmidt, 2011).

Food security, nutrition and health Vulnerability to poverty and food insecurity varies across Ethiopia's regions (Table 4) and is related to factors such as distance to input and output markets; access to productive assets; size, quality and productivity of land; household education levels and climatic factors (Nicholas *et al.*, 2021, Stefanie *et al.,* 2022). Households headed by women are particularly vulnerable, since, compared to men, they are less likely to own land and receive education (Flávia *et al.*, 2022). The moisture-reliable lowlands, pastoral areas and drought-prone highlands are among the region's most vulnerable to food poverty. Although it may seem counterintuitive that the moisture-reliable lowlands are vulnerable to food poverty, the region is classified as having the greatest proportion of poor people in the country (Hill and Porter. 2016; Kifle, 2021). In the pastoral and drought-prone highlands, in addition to poverty, lack of assets and low education; exposure to climate shocks is also high. The different administrative regions of Ethiopia have various population densities, resources, opportunities and culinary habits, and consequently differ in many aspects of food security. About 10% of the population live in pastoral and semi-pastoral communities that occupy 60% of the land. These communities live in agriculturally marginal lowlands that are prone to frequent drought and famine. On the other hand, communities in the central highlands maintain sedentary agriculture, which is based on crops and livestock. Thus, assessments status in the different regions are required in order to tailor food aid programmes to the Ethiopian geographic, demographic and cultural diversities (USAID. 2017; Nicholas *et al.*, 2021).

The regional needs are variable. Some of the highest prevalence rates of malnutrition were found in the food-surplus regions of the country, indicating what is already known: food availability is only one component of food security and not the only determining factor ensuring adequate nutritional status. Therefore, for some regions, a short-term tailored food aid could compensate for the lack of available foods, whereas others could benefit more from health and nutrition education or agricultural assistance with (Taffesse *et al.*, 2013; Nicholas *et al.,* 2021). Development program focusing on education, industrialization, water supply, sanitation, transportation and communication are required for all of the regions.

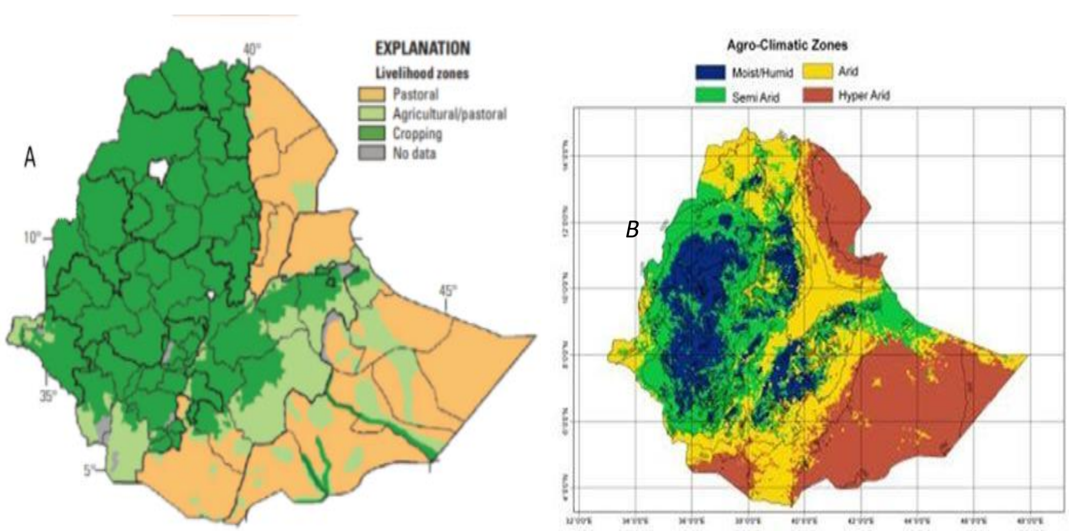

Figure 5. Ethiopian basic livelihood designations (A) and Agro-climatic Zone (B)

Food insecurity the intervening cause of malnutrition and famine. The food security situation in Ethiopia has been extremely precarious for some eight million people due to the combination of environmental, socio-political and developmental instabilities. Drought is a recurrent feature of the climate of Ethiopia, and its effects are severe since the agriculture is predominantly rain-fed. Under the existing fragile circumstances in Ethiopia, the drought has taken even a greater toll. Lack of food in the household imposes inordinate strains on the daily burdens of its members (Table 5). Coping mechanisms have been eroded in many households due to significant depletion of assets and displacement (African Development Bank, 2021; FAO, 2021).

Challenges for the agricultural sector. The agricultural sector in Ethiopia is faced by a number of challenges, centered largely on increased pressure over natural resources (driven by a rapidly growing population and demand for food), which has led to land degradation on over 40 million hectares of land (Negra.2014), declines in soil fertility and high rates of soil erosion, particularly in the highlands. In addition, low agricultural yields have been associated with unfavorable climate conditions in some parts of the country (including climate shocks such as droughts and floods), which have had adverse effects on the natural resource base as well as on the livelihoods of rural populations who have limited resource's ability to invest in resilience building and adaptation strategies (Hadgu *et al.,* 2019; Francis *et al.*, 2022; Kassaye *et al.*, 2022).

Challenge of Ethiopian Rainfed Agriculture. Ethiopian agriculture is predominantly agrarian society and the majority of population in the country is engaged in the agriculture. For Agriculture in Ethiopia contributes 4% in GDP, and account about 80% of export and 80% the labor force employment (Singh, 2019). Ethiopian has a great agricultural potential because of its vast areas of fertile hand, diverse climate generally adequate rain falls and large labor force. Inspite of this potential, however, the Ethiopian agricultural remained under developed because of Drought (USAID, 2017; Shiferaw, 2021).

The impact of climate change on agriculture in developing countries is day by day increasing. As a consequence, many African countries whose economies are largely based on weather sensitive agriculture are vulnerable to climate change. This vulnerability has been demonstrated by the devastating effects of recent flooding and various prolonged drought in the 21th century. It is widely recognized that climate change and occurrence of extreme weather conditions among the major factors affecting the agricultural production, and higher temperature and changing precipitation levels cause to climate change would decrease crop yield in Africa.

Ethiopia thus the impact of climate change is determined to countries that depends on agriculture as the main live hood (Edward Jones 2007; USAID. 2015). Climate change causes climate variability of temperature and precipitation as well as the frequency and severity of weather events direct effect the climate change includes change in solid moisture land and water condition, change in frequency of fire and pest infect and the distribution of disease, the potential for system to sustain advert impact on agriculture is determined by its capacity to adopt the changes. Vulnerability is not the same for populations living under different social, economic, political, institutional and environmental conditions. For example, pastoralists in Borana, some part of Hararghe and Low land area of Bale zones tend to be more vulnerable to climate change than farmers (MoA, 2022)

Challenge of Ethiopian irrigation practice. The major problem of crop production in Ethiopia is the low productivity due to the lack of irrigation, infectious disease and insects' control, heavily dependency on the rain fall and shortage of techniques for proper conservation and utilization of water for full and supplemental irrigation caracal stage of crops. In Ethiopia In previous years, there has been a focus on small and large irrigation schemes, many of which have failed (Gebul, 2021). Much research has been conducted into why this has happened. But a factor often unrecognized in official irrigation policy is the rapid rise from irrigation user. Farmer-led irrigation is not centered on organized schemes but is driven by individual farmers investing in technologies with which to access water for irrigation (Eshete *et al.*, 2020; Gebul, 2021). Ethiopian agricultural systems and governments do not have policies to deal with this new reality of irrigation. Policies focused on integrated water resources management do not account for the current complexities of irrigation patterns (Gebul, 2021). They work on the basis of bringing together water users and stakeholder groups, who may have shared interests or can discuss their interests and share water in collective institutions. Irrigation users are not going to work like that. It is a much more differentiated and individualized process, and the types of laws and regulations that we have around water at the moment are not fit for purpose (USAID. 2017; Hadgu *et al.,* 2019). External actors in Ethiopia are making policy recommendations that are not based on detailed, contextual knowledge of how systems are evolving and changing. Ethiopian governments, who often have an interest in external funding, are making policy for the consumption of outsiders and not for the actual complexities of how their agriculture systems are changing and evolving (USAID. 2017; Gezie, 2019; Rishikesh, 2022). Policies also tend to be made based on fantasies of large-scale production, reductions in smallholder agriculture, and reframing of agriculture towards export-led production. That is not the nature of most production in Ethiopia at least, not yet. Therefore, policies need to speak to the complex and increasingly differentiated realities of Ethiopian rural livelihoods. There is a need to change the way we engage in policy processes. Donors, external players, and researchers need to take a step back from making policy recommendations when and if they do not understand the rich, detailed complexity of agricultural systems. Ethiopian Ministry of Agriculture (MoA) need to work with the reality of those systems rather than assuming that blanket policy recommendations are going to be possible or even transformative (USAID, 2017).

Gender and age role on Ethiopian smart agriculture. Climate change has an impact on food and nutrition security and agriculture, and the agriculture sector is one of the largest emitters of greenhouse gases. It is crucial to recognize that climate change affects men and women differently. The initial assumption is that social differences, particularly gender inequality especially, in developing country, must be taken into account to strengthen the effectiveness and sustainability of CSA interventions. Women are key players in the agricultural sector, yet compared to men, they own fewer assets and have access to less land, fewer inputs, and fewer financial and extension services (FAO, IFAD, WLB, 2015; Acosta *et al.*, 2021).To avoid agricultural development and climate change adaptation strategies that may bring unintended negative consequences for women, or for certain groups of women, more in-depth gender studies need to be conducted which included examinations of the intersections between gender and other social dimensions (Acosta *et al.,* 2021).

Understanding intersectionality is also of paramount importance in contexts such as in horn of Africa where climate-induced migration, which is predominantly males who are Pastoralist, is leaving women's in charge of managing, on their own, the households and farms with reduced resources and labor, contributing to further widening their vulnerability (Khatri *et al.*, 2020; African Development Bank, 2021; FAO, 2021).

Current challenges facing the global food system. The food system is expected to provide safe and nutritious food to a population that highly grow today. Not only will there be more mouths to feed, but as incomes grow in emerging and developing economies, so too will the demand for meat, fish, and dairy (FAO, 2016; USAID, 2017).

However, food production is only one aspect of the food system. The agro-food sector also provides a livelihood for millions of people. Globally, most of the people living in extreme poverty are in rural areas where food production is often the most important economic activity. There are an estimated 570 million farms worldwide today, and millions of other people work in food-related jobs. The global food system also has a large environmental footprint. In fact, agriculture occupies nearly 40% of the earth's surface, far more than any other human activity. In addition, irrigation of agricultural crops comprises 70% of global water use, and agriculture directly contributes to around 11% of global greenhouse gas (GHG) emissions (mostly through cattle). Expanding agricultural land can also lead to deforestation, additional GHG emissions, and a loss of biodiversity (USAID. 2017; Simone *et al.*, 2019; Shiferaw, 2021).

Table 4. Food security in Ethiopia's regions (Kaluski *et al.*, 2001)

Ethiopian Region	Food security components: Availability	Accessibility	Adequacy	Estimated populationin 2000/needs
Tigray	Decrease in crop production due to delayed rainfalls.	High cereal prices. Low livestock prices. Increased food aid	Stable in nutrition status	1047 400 (34% of the rural population)/ infrastructure, food based approaches
Afar	40% decrease in production of maize, sorghum and teff due to black beetle infestation	Improvement in livestock prices due tomilitary demand. High grain prices	Pervasive childhood malnutrition, Endemic malaria, tuberculosis and anaemia	272 704 (24% of the rural population)/ nutrition education, provision of grains
Amhara	Crop affected by environmental hazards. Disruption of relief distribution,inadequate rations and poor targeting	Livestock death in dry months with distressed/reduced sales of livestock earlier in the season. Declined charcoal prices, and Declining wages	Endemic malaria in lowland. Anticipated epidemic with rains.	2 534 915 (17% of the rural population)/ food-based approaches, infrastructure, public health measures and health care
Oromia	Decrease in usual surplus of maize affecting inter-regional grain flow with food security consequences for grain deficit in neighboring regions, such as Amhara	Increased grain prices. Decreased charcoal and livestock prices. Average wages lower due to increased supply of labour. Decreased coffee production due to coffee berry disease	High malnutrition rate, especially in elderly and lactating mothers	1 186 966 (7% of the rural population)/ food-based approaches, SFP, GFP
Somali	Poor food security associated with migration to urban areas. Adverse climatic conditions	Continuation of poor trade for pastoralists. Low nutritional status of livestock. Poor infrastructure affectingthe overall situation	Major outbreaks of bloody diarrhoea and malnutrition-related diseases	1 321 000 (42% of the rural population)/ infrastructure, food-based approaches,SFP, GFP
Benshangul Gumuz	Normal production of maize, sorghum and teff. Mostly virgin land with potential shifting cultivation	Mixed agriculture, together with crafts and gold mining, stabilise the region with favourable food security	No outbreaks reported in the region.Malaria continues to be endemic	4201 (1% of the rural population)/ infrastructure
SNNPR	Crops suffer from insufficient rains. Alarming food availability in Konso	Low grain supply. Increased livestock supply with decreasing prices. High population pressure in most parts	High malnutrition rate	760 500 (7% of rural population)/ food-based approaches, GFP, SFP
Gambella	Chronic poor availability and lack of access to markets. Estimated crop production to cover only half of the annual food needs	Declining purchasing power with households at risk of food shortages	Acute diarrhoea, most probably due tocontaminated river water	46600 (27% of the rural population)/agriculture assistance, infrastructure

Harari	Decrease in sorghum (the major crop)due to rainfall anomalies	Livestock prices within normal range. Declined crop prices. Improvement in trade, including chat	No significant health problems and outbreaks reported. Endemic malariain	7070 (11% of the rural population)/ infrastructure
Dire Dawa	Reduced cereal yield	Increased livestock prices. Declined charcoal sales (the main source of income in times of distress)	No indication of severe malnutrition.Endemic malaria	47459 (53% of the rural population)/ food-based approaches, infrastructure

Table 5. Food and nutrition key indicators in a geographical information system

Food availability	Food accessibility	Food and nutrition adequacy	Health and nutrition status
• Food production, food distribution • Weather and early crop condition(pest and disease) • Harvest, expected yield • Food balance sheet, dietary energy supply • Alternative food sources • Policy affecting production • Political instability • Rainfall • Irrigation	• House hold income and purchasing income • Price to income ratio • Price of common staples • Price distribution over the Year • Access to safe water and to adequate sanitation • Policies affecting rations and subsidies • Transportation and roads conditions	• Food frequency of key items consumption • Frequency of items typical to shortages • Average energy intake • Average food intake of major food groups Percentage of energy • Percentage of protein from animal source • Prevalence of exclusive breast-feeding for six months • Prevalence of infants 6 – 12 months breast-fed and types of complementary feeding - Perception of adequacy (hunger) - Crop quality	• Infant mortality rate • Under five mortality rate • Maternal mortality rate • Immunisation rate for measles, tuberculosis, diphtheria, tetanus and poliomyelitis • Tuberculosis & sexually transmitted disease • Iron-deficiency anaemia rate • Goitre rate Infants and children • Low birth weigh • Weight-for-height (*Z*-scores) and BMI for age • Underweight and Stunting

The world is undergoing changes that will shape the livelihood of millions of people in the coming years. Understanding the root causes of the various trends (Table 6) and the relationship between them will aid manage the demand in solutions for future food security and sustainable livelihoods for everyone, in the changing world. Variables to describe the trends that cover both environmental and socio-economic aspects (Table 6). This section further describes the reason behind the uncertainty of future food and agricultural systems, providing quantitative evidence on the broad range of interlinked factors and trends, (e.g., resource availability and productivity; climate change; productivity and technological change; conflicts, crises and natural disasters; population dynamics; the behavior of producers and consumers, and trade and policy responses).

Future policies may require new recipes. Agriculture and food systems have already changed significantly, but will need to adjust further in this evolving global environment (FAO, 2017; USAID, 2017; Singh, 2019) Just like a good meal is a balanced meal, good policies will need to strike a balance between the different objectives of the triple challenge facing the global food system today. And just like a good meal depends not only on the chef, but also on the quality of the ingredients so too will good policies depend not only on the policy maker, but also on the input from many stakeholders. Given the scale and complexity of these challenges, policy makers may need to experiment with new recipes to cook up a set of policy solutions that are to everyone's taste (FAO, 2017; Fentie *et al*., 2021; Calicioglu *et al.,* 2019).

Potential CSA Practices for Smallholder Farming Systems. In order to increase the productivity of small-scale agriculture in a sustainable way, appropriate agronomic management practices and suitable technology are needed (Tessema and Simane, 2019). This should be linked with the mitigation of climate change impacts and other relevant environmental problems (e.g., soil degradation, soil erosion, water shortages, salinization) (Aweke, and Gelaw, 2019; Bai *et al.*, 2019). In Ethiopia, several CSA practices are applied in smallholder farming systems (Table 7) and their current status and future potential are discussed in this section.

Financing opportunities for CSA in Ethiopia. In Ethiopia there are numerous international development agencies that are working with government and civil society organizations in climate change mitigation and adaptation, as well as in areas related to the implementation of CSA. Some of the key agencies are the World Bank, FAO, GIZ, WFP and USAID (USAID, 2017; Romain *et al.*, 2021).

Climate Change Forum Ethiopia is a multi-stakeholder group that meets regularly to discuss national responses to climate change. It serves a broader coordination function by bringing together government, national and international NGOs, academia and research institutes, and bilateral, regional and multilateral donors to meet and cooperate on a wide array of climate change-related issues. The UN Climate Change Conference COP 26 in Glasgow, United Kingdom is a crucial opportunity to achieve pivotal, transformational change in global climate policy and action. The COP 26 comes against the background of widespread, rapid and intensifying climate change impacts, which are already impacting every region on Earth and serve as the meeting of the Parties to the Kyoto Protocol (CMP 16) (UNFCCC, 2021). Accordingly, Some of NGOs have been also implementing climate change adaptation agricultural activities in across Ethiopia regions. Climate change-related activities of the NGO include biological soil conservation, physical soil conservation, water harvesting and small-scale irrigation, and promotion of horticulture crops for livelihoods diversification.

Table 6. Trends relating to future agriculture and food systems (FAO, 2017)

Challenges for food stability and availability	Challenges for food access and utilization	Systemic challenges
1. Sustainably improve agricultural productivity to meet increasing demand.	1. Eradicate extreme poverty and reduce inequality.	1. Make food systems more efficient, inclusive and resilient.
2. Ensure a sustainable natural resource base.	2. End hunger and all forms of malnutrition.	2. Address the needs for coherent and effective national and international governance.
3. Address climate change and intensification of natural hazards.	3. Improve income-earning opportunities in rural areas and address the root causes of migration.	
4. Prevent transboundary and emerging agriculture and food system threats	4. Build resilience to protracted crises, disasters and conflicts.	

Table 7. CSA Practices for smallholder farming systems in Ethiopia (FAO, 2016).

CSA Practices	Main Components	Why It Is CSA
• Conservation agriculture • Integrated nutrient management • Agroforestry (AF) • Water harvesting and irrigation	• Reduced tillage Crop residue management • Crop rotation/intercropping with cereals and legumes Diversifying cropping systems • Compost and manure management, including green manuring • Efficient fertilizer application techniques (time, place, method) • Combined use of inorganic fertilizers, locally available organic matter, and soil amendments • Tree-based conservation agriculture • Traditionally practiced AF • Improved types of AF • Rainwater and runoff harvesting Sm all-scale irrigation • Traditional irrigation systems	• Sequesters soil carbon and reduces greenhouse gas (GHG) emissions • Improves soil fertility • Enhances resilience to dry and hot spells • Sequesters soil carbon • Increases soil resilience to drought • Improves soil fertility • Reduces nutrient leaching Reduces GHG emissions • Increases agricultural productivity • Sequesters soil and biomass carbon • Supports resilience to drought • Increases agricultural productivity • Increases water availability • Enhances resilience to dry and hot spells • Increases agricultural productivity

Lastly, while various CSA-related programmes are being undertaken and various institutions are involved in CSA-related activities, there is still need for improved coordination of all actors, particularly in linking government initiatives with civil society initiatives (Changwei and Wang, 2021, Kassaye *et al.*, 2022). The conservation agriculture task force supported in recent years could be expanded and given a more prominent role and permanent seat as a climate-smart agriculture coordination unit within the Ministry of Agriculture. In addition, moral, financial and technical support to the activities of the Ethiopia Climate-Smart Agriculture Alliance could help reach farmers and locations not currently targeted under other CSA- related programmes and projects in the country (USAID. 2017).

CONCLUSION AND RECOMMENDATION

There is willingness and commitment from the government to reduce poverty and ensure food security while addressing climate change. Ethiopia government has developed policies and strategies that are pertinent to ensure food security as well as address climate change. Ethiopian government has moreover ratified international climate change-related conventions.

This provides a good opportunity for large-scale implementation and promotion of climate-smart practices such as agroforestry, conservation agriculture, off season Agricultural Practices. There are private sector organizations and numerous NGOs in the country. At grassroots level there are also adequate numbers of extension and development agents to create climate-related awareness, provide capacity-building training and promote climate-smart agricultural activities.

Figure 6. International funds actually accessed by different institutions for CSA purpose

Conservation Agricultural (CSA) needs to be mainstreamed into core government strategies, guidelines, manuals and annual action plans. Priority needs to be given to CSA practices that bring productivity gains, enhance resilience and reduce emissions. For effective CSA promotion, adequate mechanisms are needed for generating, capturing, and disseminating knowledge and information through the use of effective processes and institutional arrangements. For CSA knowledge dissemination a comprehensive capacity development approach for all stakeholders that builds on a sound assessment of needs is required. In this regard, within the diversified extension service delivery, there is a need to build the capacity of all CSA and/or conservation agriculture-implementing organizations, with major emphasis on the extension of the MoA and integration of CSA conservation agriculture into the country's extension package. It is through the extension system that the technologies reach the wider community.

It is important to have a proactive platform for governmental institutions, NGOs, donors, private sector and civil society organizations in Ethiopia to fill gaps and enhance collective action on CSA. A wide range of measures are required to reduce the livestock sector's climate-change responses. These include improving production and feed systems, breeding low methane-emitting ruminants and introducing manure management methods that reduce emissions. Efforts should be made towards implementing restricted grazing to avoid overgrazing, which causes degradation, and crop residue removal through open grazing. CSA has to be integrated into tertiary level education, including TVET colleges and universities, so as to develop a large number of professionals with an in-depth knowledge of the subject. The CSA value chains need to be evaluated and strengthened in order to enable access to key inputs and equipment needed as well as enabling the sale of CSA produce, particularly legumes used in rotations and intercropping.

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The Authors declare no conflict of interest in the paper.

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