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CLIMATE-SMART AGRICULTURE INVESTMENT PLAN

ZAMBIA

Analyses to support the climate-smart development of Zambia's agriculture sector

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1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

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Foreword

In Zambia and other Sub-Saharan African countries, agriculture systems face a growing number of climate-related vulnerabilities. Climate has become increasingly variable over the past few decades, with drought, seasonal and flash flooding, and extreme temperatures occurring more frequently. In response, the World Bank is collaborating with the Government of Zambia to integrate climate change considerations into the country's agriculture policy agenda through a Climate-Smart Agriculture Investment Plan (CSAIP).

The CSAIP aims to produce evidence of climate-smart agriculture (CSA) technologies that offer the greatest potential as Zambia seeks to sustainably increase productivity, enhance household and agroecosystem resilience, and reduce or remove its greenhouse gas emissions. Going forward, it will be critical to have an understanding of how best to address the trade-offs and synergies between achieving agricultural and economic goals on one hand, and preparing for emerging climate challenges on the other. The use of evidenced-based decision making is a key part of this process.

Zambia's CSAIP is the outcome of a partnership between Zambia's Ministry of Agriculture and the World Bank. The CSAIP represents a commitment by the Bank's Agriculture Global Practice under the Eighteenth Replenishment of the International Development Association (IDA18) to support development of 10 country-level CSA strategies and investment plans. The CSAIP builds on existing strategy documents, including Zambia's 7th National Development Plan and its National Agricultural Investment Plan. Through a process that combines several modeling approaches, technology foresighting, and consultations with stakeholders in the public and private sectors, civil society, and farmer groups, we hope to answer these vital questions:

- Can CSA deliver on key agriculture sector indicators by 2050?
- Are CSA benefits robust across a range of climate change scenarios?
- Which CSA technologies should be prioritized for scale up?
- Which strategies and investments will be critical to enable broad adoption of CSA technologies?

In view of the risks as well as opportunities inherent in a future with changing climate and uncertainty, we consider Zambia's CSAIP to be an integral tool in bringing about sustainable improvement in the lives and livelihoods of those that most need it—the smallholder farmers—many of whom are living below the poverty line and who make up more than half of Zambia's total population.

Julius J. Shawa
Permanent Secretary
Ministry of Agriculture, Zambia

Paul Noumba Um
Country Director (Botswana, eSwatini, Lesotho, Namibia, South Africa, Zambia, Zimbabwe)
The World Bank Group

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The report "Zambia Climate-Smart Agriculture Investment Plan" was developed by a core team from the World Bank and Ministry of Agriculture of the Republic of Zambia. Dominic Namanyungu led the Climate-Smart Agriculture Technical Team, which consisted of Joy Sinyangwe, Douglas Mwasi, Morton Mwanza, Justin Chuunka, Reynolds Shula, and Sipawa Songiso. The World Bank Group core team consisted of Christine Heumesser and Alex Mwanakasale (both Task Team Leaders), Willem Janssen, Martin Wallner, Ngao Mubanga, all of the World Bank's Food and Agriculture Global Practice. Both teams were greatly supported by Mick Mwala throughout the period of the study.

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Abbreviations

7NDP	Seventh National Development Plan
AEZ	agroecological zone
AF	agroforestry
AFOLU	Agriculture, Forestry, and Other Land Use
BAU	business-as-usual
CA	conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CBA	cost-benefit analysis
CE	carbon equivalents
CH_4	methane
CO_2	carbon dioxide
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
COMACO	Community Markets for Conservation
CSA	climate-smart agriculture
CSO	Central Statistical Office
CSAIP	Climate-Smart Agriculture Investment Plan
CPF	Country Partnership Framework
DiD	difference in difference
DIV	crop diversification
DTM	drought-tolerant maize
dM	dry matter
EPIC	Environmental Policy Integrated Climate Model
EX-ACT	Ex-Ante Carbon balance Tool
EIRR	economic internal rate of return
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FFS	farmer field school
FISP	Farmer Input Support Program
FRA	Food Reserve Agency
G4M	Global Forest Model
GCM	General Circulation Model
$GgCO_2e$	Gigagram of carbon dioxide equivalent
GHG	greenhouse gas
GLOBIOM	Global Biosphere Management Model
GoZ	Government of the Republic of Zambia
GDP	gross domestic product
Ha	hectare
IAPRI	Indaba Agricultural Policy Research Institute
ICTs	information and communications technologies
IIASA	International Institute for Applied Systems Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INDC	Intended Nationally Determined Contribution
LCMS	(Zambia) Living Conditions Monitoring Survey
LPJmL	Lund-Potsdam-Jena managed Land model
LULUCF	land use, land-use change, and forestry
MFD	Maximizing Finance for Development
MSD	minimum soil disturbance
MT	metric ton
$MtCO_2e$	mega tons of carbon dioxide-equivalent
MoA	Ministry of Agriculture
NAIP	National Agriculture Investment Plan
N_2O	nitrous oxide
NGO	Non-Governmental Organizations
NDC	Nationally Determined Contribution
NAESS	National Agricultural Extension and Advisory Services Strategy
NPV	net present value
OLS	Ordinary Least Squares
PHL	post-harvest loss
RALS	Rural Agricultural Livelihood Survey
RCP	Representative Concentration Pathway
RR	residue retention
SPAM	Spatial Production Allocation Model
SSP	Shared Socio-economic Pathways
tCO_2e	metric tons of CO_2-equivalent
WFP	World Food Programme
WII	weather index insurance
ZARI	Zambia Agriculture Research Institute
ZMK	Zambian Kwacha

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ES

Executive Summary

Key messages

- Most climate-smart agriculture (CSA) practices have positive welfare effects on Zambian households in the long-term; in the short-term benefits seem uncertain and may be hindered by high upfront and labor cost. Tailoring CSA to site-specific, agroecological conditions is critical.
- Projections until 2050 show that Zambia's agriculture sector could achieve or surpass sectoral development goals such as increasing crop and livestock production, food availability, and net trade. CSA practices can further increase these positive effects, reduce Zambia's trade deficit in certain commodities, and, in addition, contribute to climate mitigation as public good.
- Climate change projections until 2050 show that yield of key crops could decrease by -25 percent, depending on agroecological zone. While CSA can increase crop yields up to 23 percent, these productivity increases are insufficient to avoid further expansion of agricultural land into forest land. Trends in deforestation put Zambia at risk of failing to achieve its climate commitments. A carbon tax on emissions from land use change could be an effective measures to halt deforestation for agriculture.
- Among the range of CSA practices, crop diversification into legumes, commercial horticulture, agroforestry, and strategies of reducing post-harvest losses seem most promising in achieving welfare and sectoral development goals. However, adoption of CSA seems constrained by inadequate access to finance, input and output markets, and capacity building.
- Business partnerships with rural communities, farmer field schools, and participatory integrated landscape management approaches seem promising and profitable mechanisms to support the development of a productive, resilient, and low-emission agriculture sector. The estimated annual investment requirements to roll out CSA to 50 percent of farmers is less than current funding for the agriculture sector, indicating that implementation quality and effectiveness are critical.
- The positive private benefits as well as public good benefits of CSA provide a strong rational to leverage public support through: support agricultural research, testing and dissemination of CSA across agroecological zones; improve access to inputs and agricultural finance; introduce policy measures for increased agribusiness participation; promote cross-ministerial collaboration to promote landscape approaches; continue policy reforms to support agricultural diversification and adoption of short-duration varieties; support the development of market infrastructure such as rural storage facilities.

Zambia's agricultural sector represents the backbone of its rural economy and holds great potential for the entire country. About 60 percent of the population depends on agriculture for a livelihood; of this subset of the population, 80 percent are classified as poor. While employment in the sector remains high, agriculture's contribution to GDP declined from 17.3 percent in 2004 to 8.2 percent in 2017, and its labor productivity from US$702 in 2004 to US$584 in 2015. Agriculture's relatively low contribution to GDP and its large share of the total Zambian labor force suggests that the sector is characterized by low-productivity and unskilled subsistence agriculture lacking access to productive assets and market opportunities. There is also very little crop diversity—maize production accounts for 70 percent of the country's cropland—a narrow focus on a few crops makes farmers vulnerable to both environmental and market shocks (World Bank 2018e, 2018a).

Zambia's agriculture sector faces challenges and is likely to grow more vulnerable as a result of climate change and risk. The country has a highly variable climate, and in the past few decades has experienced climatic extremes in the form of droughts, seasonal and flash floods, and extreme temperatures. Many of these events occurred with increased frequency, intensity, and magnitude. It has been estimated that droughts caused US$438 million in agricultural sector losses; excessive rainfalls and floods had an US$172 million impact between 1982 and 2016. Over the next 10 to 20 years, climate change-related losses in agriculture are expected to amount to US$2.2–3.1 billion (Braimoh et al. 2018, World Bank 2018a).

At the same time, land use, land-use change and forestry (LULUCF), and agriculture sector account for approximately 93 percent of the country's carbon footprint. Zambia contributes only three quarters of a percentage point to global emissions. In the national emissions profile, the agriculture and LULUCF sector represent 7 percent and 86 percent of emissions, respectively. Most emissions arising from LULUCF sector are a result of biomass burning, including charcoal production. Agriculture's direct contribution to greenhouse gas (GHG) emissions may seem small but doubles to 13 percent if its indirect effects—through the expansion of cropland and grassland—are considered (CIAT and World Bank 2017).

The Government of the Republic of Zambia (GoZ) is integrating climate change concerns into its agriculture policy agenda. Zambia has developed several climate change-related policies and strategies, and the mainstreaming of climate change into sectoral policies is expected to continue. The National Climate Change Response Strategy (2010) emphasizes the role of sustainable land use systems in enhancing food security. Zambia's Nationally Determined Contribution (NDC) sets ambitious goals for climate mitigation and adaptation that include the agriculture sector, and which aim to reduce GHG emissions by 25 percent up to as much as 47 percent, depending on the level of international support and financing.

Under its Zambia Climate-Smart Agriculture (CSA) Strategy Framework, the GoZ is promoting the rollout of climate-smart agriculture practices that will sustainably increase productivity, enhance resilience, and reduce or remove GHG emissions. The CSA concept reflects an ambition to improve the integration of agricultural development and climate responsiveness. However, CSA implementation will require planning to minimize trade-offs and enhance synergies (co-benefits and "triple-wins") among the three CSA pillars: productivity, adaptation and resilience building, and mitigation. The Zambia Climate-Smart Agriculture Strategy Framework identifies opportunities and constraints for CSA implementation. However, to achieve the goal of broad CSA adoption, it suggests that more evidence will be needed of CSA's potential benefits at the local and national levels, specifically in response to climate change, as well as improved communication about CSA benefits.

The Climate-Smart Agriculture Investment Plan (CSAIP) aims to identify and fill knowledge gaps about CSA's local- and national-level benefits, specifically under climate change, inform policy

development, and prioritize investment opportunities. The World Bank collaborated with the GoZ to develop a CSAIP intended to support the operationalization of the country's climate commitments toward development of a productive, resilient, and low-emission agriculture sector. The CSAIP draws on the goals of established policy and strategy documents and analyzes whether and how CSA can help Zambia achieve its agriculture sector goals and climate mitigation goals. Thus, the CSAIP provides quantitative assessments of CSA's potential benefits in the event of climate change, and provides evidence how CSA can benefit rural households. The analysis concludes with the prioritization of CSA practices and suggestions for future investments in CSA. The CSAIP is expected to inform forthcoming strategies and programs, such as the Second National Agriculture Investment Plan (NAIP), the implementation of the Seventh National Development Plan (7NDP), the development of the NDC implementation plan, as well as existing and future donor projects.

The CSAIP development began with a participatory process that identified the agriculture sector's policy goals. This report takes the next step by assessing the impacts of a suite of CSA practices on achieving the sector goals and on household welfare. The report concludes with recommendations and proposals for future CSA investments. Drawing on existing policy frameworks, and informed by two in-country stakeholder workshops, a vision for the agriculture sector was established that focuses on increased productivity, climate resilience, and mitigation co-benefits. Specific, measurable targets were identified for the year 2050 that align with the vision and which can be used to evaluate alternative development pathways (see Table ES.1). The CSAIP assessment was guided by following questions: (i) What is the impact of CSA adoption on agriculture sector indicators under climate change? Can CSA practices enhance the feasibility of achieving the agriculture sector vision compared to conventional practices? (ii) What is the impact of CSA adoption on household welfare? (iii) Which CSA strategies should be prioritized for scale up according to quantitative impact indictors (iv) Which delivery mechanisms and investment opportunities can be considered to support a broad rollout of CSA in Zambia and what are the related costs?

Table ES.1 Quantified targets that align to the agriculture sector vision and alignment to CSA pillars

Source/Policy	Target	CSA pillars
Normative vision as developed in stakeholder workshops		
Stakeholder workshop	By 2050, double yields and profits by means of diversification (beyond maize), while ensuring household food and nutrition security	Productivity
Stakeholder workshop	By 2050, have an agriculture sector that is: (i) diversified in crop production; (ii) diversified in age and gender of its workforce; and (iii) able to cope with economic and climatic shocks through enhanced capacity and policy	Resilience
Stakeholder workshop	By 2050, increase agricultural productivity while maintaining a low ecological footprint	Mitigation
Quantifiable targets to achieve the long-term vision		
National Agriculture Investment Plan (2014–2018)	Increase the share of agricultural exports as a percentage of non-traditional exports from 41% in 2011 to 55% by 2018	Productivity
	Increase production of cereals from 3.2 million metric tons (MT) to 6.0 million MT by 2018	Productivity
National Long Term Vision 2030	Increase land under cultivation by 900,000 hectares (ha) by 2030	Productivity
	Increase livestock population to 6,000,000 by 2030	Productivity, Resilience
National Policy on Environment (2007)	Sustainably intensify land use without converting additional land area into agricultural land	Resilience, Mitigation
Nationally Determined Contribution (2015)	Reduce GHG emissions by 25% with limited international support or 47% conditional on the receipt of US$35 billion of international assistance	Mitigation

The CSAIP's analytical approach is innovative and combines quantitative models and qualitative assessments to expand the current body of research. The quantitative modeling, this is, the partial equilibrium agriculture sector model Global Biosphere Management Model (GLOBIOM) which was adjusted to the Zambian context, an econometric approach, and a cost-benefit analysis, was allied to stakeholder engagement and a literature review . This allows to assess the impact of a suite of CSA practices on household-level welfare, achievement of sector goals, as well as the economic returns of scaling up CSA through varied investment models. GLOBIOM allows to assess CSA's performance under alternative future scenarios, including a business-as-usual (BAU) scenario without climate change and alternative climate change scenarios, through 2050. Table ES.2 provides an overview of which CSA practices were considered most important by stakeholders and which quantitative methods are employed for the assessment of their impacts. The qualitative analyses were useful in assessing the state of Zambia's enabling environment, innovative delivery mechanisms to enhance CSA adoption, and funding requirements.

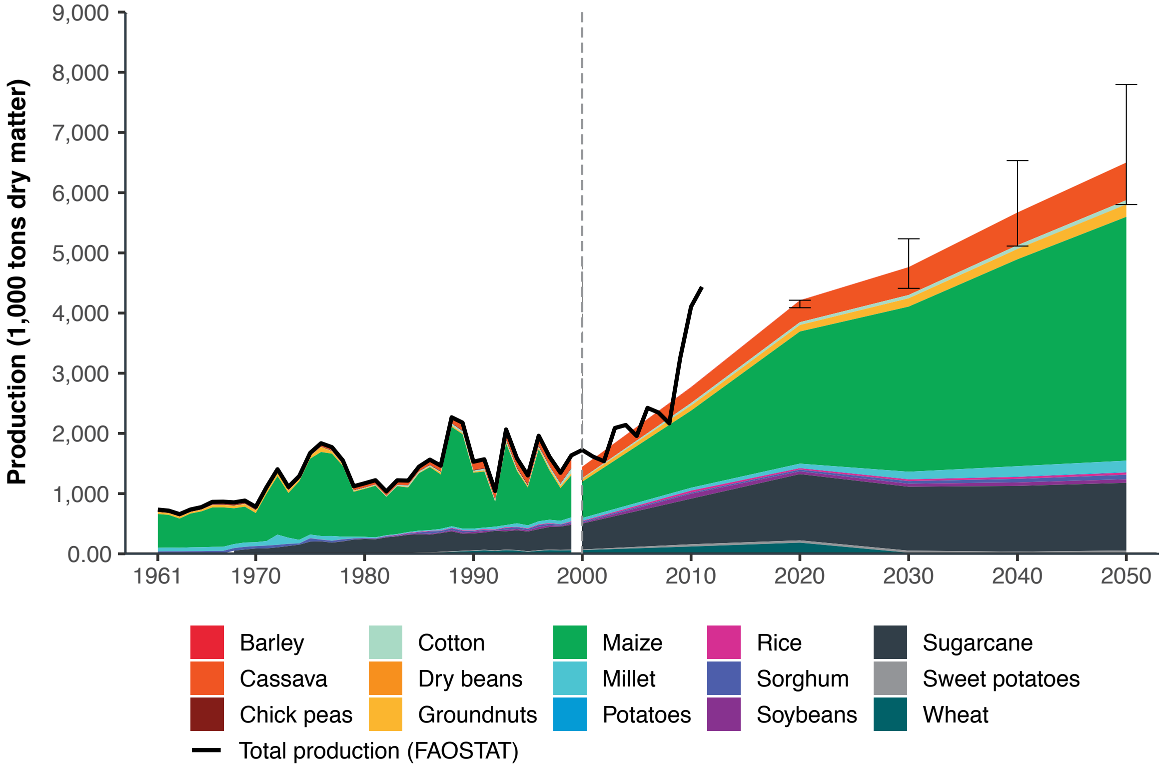
Table ES.2 Evaluation of CSA practices using key modeling approaches

CSA Practice	Household level			Sector level
	Econometric analysis	Cost-Benefit Analysis: Financial analysis	Cost-Benefit Analysis: Economic analysis	GLOBIOM
Conservation agriculture's 3 pillars:				✓
Minimum soil disturbance	✓	✓	✓	✓
Residue retention	✓	✓	✓	✓
Legume rotation / intercropping	✓	✓	✓	✓
Agroforestry	✓	✓	✓	✓
Commercial horticulture	✓			
Crop diversification	✓			✓
Livestock diversification	✓			
Drought-tolerant seeds	✓			✓
Timing of planting	✓			
Agricultural liming	✓			
Reducing post-harvest loss				✓

The analysis shows that CSA's impact on household income and welfare indicators is mostly positive in the long term. In the short term, the incentive to adopt CSA is constrained by high upfront and production costs. Positive impacts on household income, increase in food availability, reduction of poverty were found in the long term. Higher production costs in the short term (that is, the need for mechanization or increased labor time) could impede adoption specifically for minimum soil disturbance, residue retention, and agroforestry. Some CSA practices do not increase income but do reduce income variability. Two exceptions are minimum soil disturbance and delayed timing of planting, both of which appear ineffective in reducing income variability.

The promotion of CSA must be customized to suit Zambia's specific agroecological conditions. The analysis shows that several CSA practices perform better under dry than wet conditions, which points toward their potentially favorable impact in the event of a drier future climate. Minimum soil disturbance, residue retention, and small-scale horticulture practices did not show good results under wetter conditions. Drought-tolerant seeds, agroforestry, and crop diversification show good results under both extreme dry and wet conditions, and seem particularly suitable for climate adaptation and building household resilience. Under dry conditions, the adoption of nearly all CSA practices has a significant positive impact on food security and crop production.

Figure ES.1 Trends in crop production under conventional practices until 2050, for projections without and with climate change (error bars)

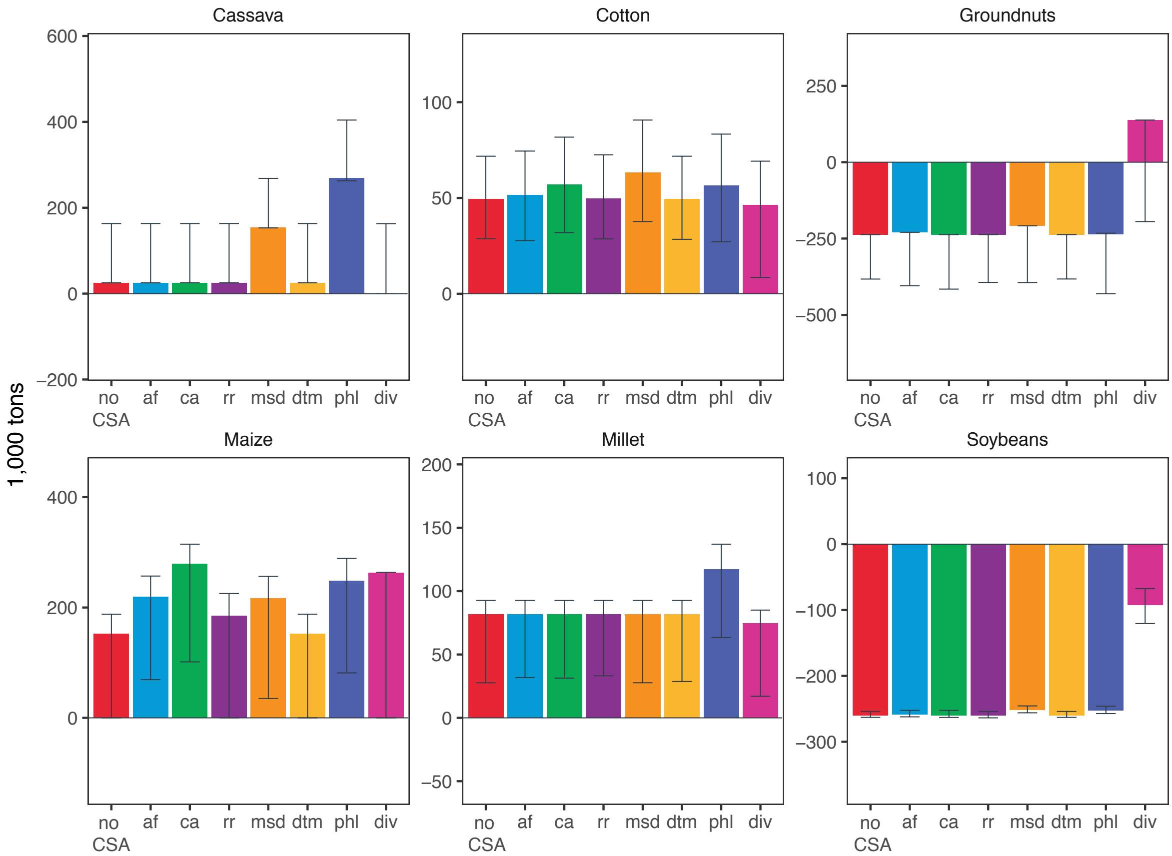


Sources: Historical values for total production are from FAOSTAT and are indicated until the year 2011; the GLOBIOM model provides projections from 2000-2050 for scenarios without and with climate change.
Note: Error bars indicate the range in total crop production as a consequence of climate change.

The adoption of CSA enhances the likelihood of achieving, and even surpassing, the agriculture sector vision for crop production and food availability by 2050. Projections are driven by increased population, GDP, and food demand, which leads to a doubling of crop production and increase in food availability, even with conventional agricultural practices. Under climate change projections, total crop production could vary from an -11 percent decrease to an increase of up to 20 percent under conventional practices (see Figure ES.1). Under climate change projections, total crop production could vary from an -11 percent decrease to an increase of up to 20 percent under conventional practices (see error bars in Figure ES.1). CSA adoption is projected to increase total production by, on average, 6 percent compare to conventional practices, and further enhance food availability by 5–10 percent. The effect on crop production varies by crop and CSA practice. For instance, promoting crop diversification could increase the production of soybeans and groundnuts by up to 200 percent. These positive effects appear to be more pronounced under climate change projections.

With respect to trade, the target of doubling net exports by 2050 is partially feasible. CSA, such as crop diversification, reducing post-harvest loss, or minimum soil disturbance, can potentially enhance international competitiveness and transform Zambia into a net exporter of additional commodities. The aim to enhance net exports by 2050 is reached for maize and millet, and—under extreme climate change scenarios—for cassava and cotton, even with conventional practices. When adopting CSA practices (see Figure ES.2), such as crop diversification, Zambia has the potential to become a net exporter of groundnuts, increase net exports of maize, and decrease net imports of soybeans by 2050, compared to a situation with conventional agricultural practices.

Figure ES.2 Effect of conventional practices and CSA on net trade in 2050, in 1,000 tons

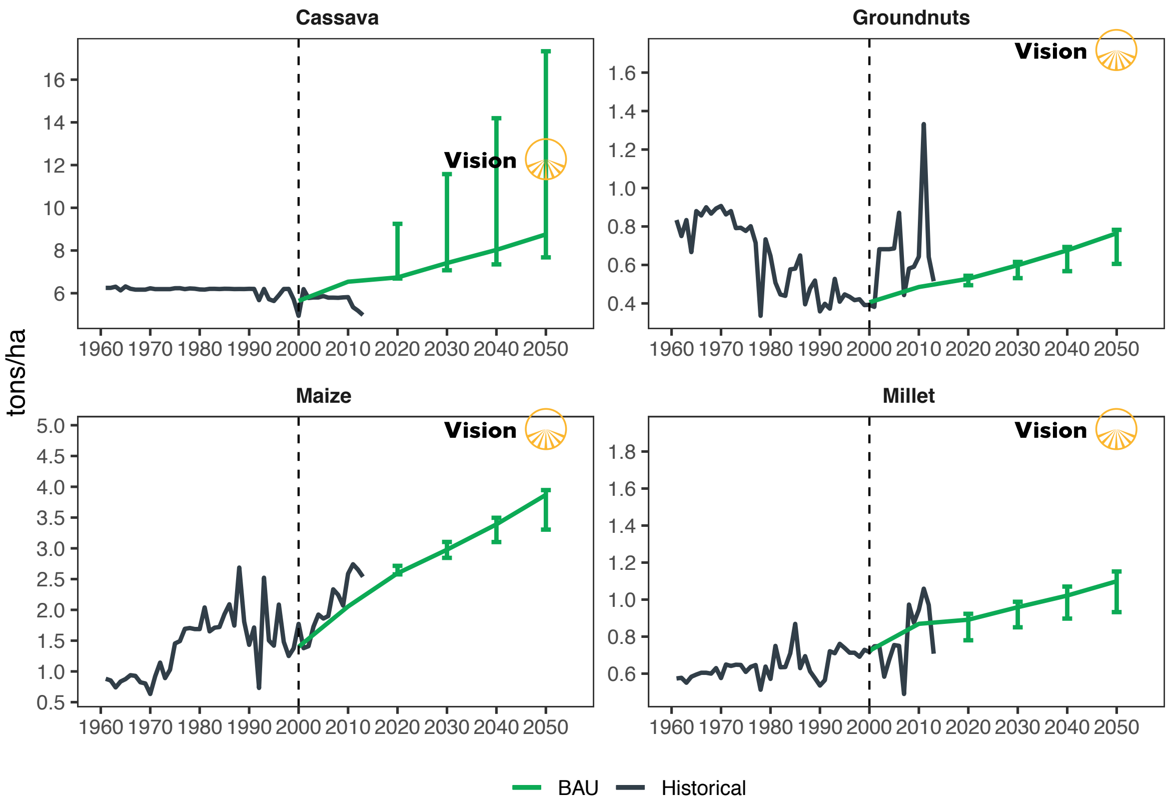


Source: GLOBIOM model results.
Note: Error bars indicate the range of net trade as a consequence of climate change; no CSA refers to conventional practices; af to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

In contrast, the doubling of crop yields will not be achieved through conventional practices until 2050. Although CSA has the potential to narrow the distance to the target of doubling crop yields, additional strategies to enhance agricultural productivity will be necessary. Under a scenario of no climate change, yields for most crops are expected to increase, but not sufficiently under conventional practices to double productivity per hectare. CSA practices with the greatest potential to reach this target are reducing post-harvest loss, conservation agriculture, and agroforestry, which are expected to increase production per hectare by 12–23 percent compared to conventional practices. Climate change is projected to have a negative impact on yields of most crops. With the exception of cassava, yields of most crops may increase less than without climate change (see Figure ES.3). In the most extreme climate change scenario, the projected maize yield is 3.3 MT/ha, 15 percent lower than without climate change. However, certain CSA practices, for instance, adoption of drought-tolerant maize, conservation agriculture, and crop diversification, are found to enhance an already positive yield effect.

Since projected crop yield increases are insufficient to reach the sector's long-term targets, there is a risk that increased production will have to come from an expansion of Zambia's cropland. CSA strategies are expected to curb the trend of land conversion, but only marginally. To meet domestic and foreign food demand, almost 2.2 million ha of mainly forested area is projected to be converted to agricultural land between 2010 and 2050, thereof converting 917,000 ha into cropland (see Figure ES.4). This scenario is just short of the target to convert no more than 0.9 million ha into cropland, as stated in Zambia's Vision 2030 (2006), but would not comply with the goal of the National Policy on Environment (2007) of completely avoiding land conversions. Individual CSA practices have the potential to reduce conversion to cropland by around 32,000 ha, in the case of conservation agriculture, and 113,000 ha in the case of reducing post-harvest losses. However, averting the conversion of forest land into cropland will not necessarily halt deforestation, as a similar land area is expected to be converted to grassland to meet increases in livestock production.

Figure ES.3 **Trends in crop yields under conventional practices until 2050, for projections without and with climate change (error bars)**

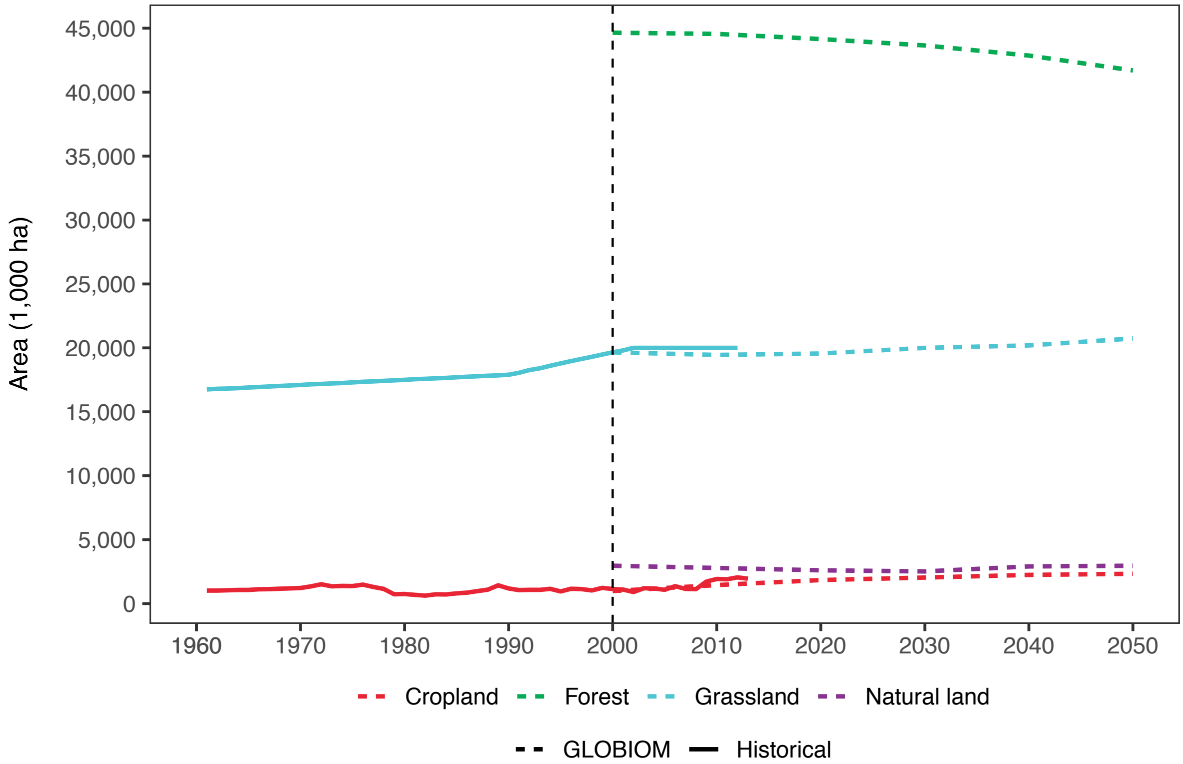


Source: Historical values are from FAOSTAT; GLOBIOM provides projections from 2000-2050 for scenarios without and with climate change; "Vision" was determined through stakeholder consultation and represents the targets for agriculture sector development in 2050.
Note: Error bars indicate the range in total crop production as a consequence of climate change.

The land use change trends are reflected in Zambia's carbon footprint and put the country at risk of failure to meet its NDC GHG emissions reduction goals of 25 percent to 47 percent. Further agricultural land expansion can be expected to continue in the future. CSA adoption can reduce emissions from land use change, but only by -0.32 percent compared to conventional practices. Minimum soil disturbance and post-harvest loss can reduce fertilizer use, while residue retention rather increases its use. The average impact on emission reduction from synthetic fertilizer is negligible compared to conventional practices. On the positive side, CSA practices are expected to enhance soil carbon sequestration and biomass growth (for instance agroforestry), which is expected to be many times more effective in reducing tons of carbon dioxide equivalent (tCO_2e) emissions than reducing consumption of nitrate fertilizer.

Introducing a low carbon tax on land conversion could effectively halt deforestation for agriculture even at very low carbon prices. But reducing biomass burning seems most promising strategy. A carbon tax of US$10/$tCO_2e$ emissions could reduce emissions from deforestation and other land use change by 99 percent in 2050 compared to a scenario without policies. At a very low price of US$5/$tCO_2e$, land conversion still appears to be profitable. As a consequence, production

Figure ES.4 Trends in land use under conventional practices, 1960-2050, for projections without climate change



Sources: Historical values are from FAOSTAT, where available; GLOBIOM provides projections from 2000-2050

and food availability would slight decrease by approximately 2 percent, crop yield slightly increases, and imports increase compared to a scenario without policies. While these policies seem promising, enforcement at this point in time is unlikely. Emissions from agriculture and land conversion related to agriculture constitute only 13 percent of total emissions in Zambia today. The largest share stems from biomass burning which is not modelled in our analysis. To get serious about reducing emissions, reducing biomass burning and charcoal use must become a policy priority.

While CSA's impact on land use change may be small in terms of hectarage and tCO_2e emissions, an economic analysis shows that the economic value of reducing GHG emissions to society is significant. If mitigation co-benefits are valued at a shadow price of carbon, that is, the carbon price which is consistent with achieving the core objective of the Paris Agreement on climate change (2015) of keeping temperature rise below 2 degrees, the net present value of sector-wide CSA intervention is increased by between 171 percent and 341 percent, or from US$170 million—if private benefits are considered—to between US$460 million and US$750 million. Even with a carbon market price of US$11/$tCO_2e$ emission, the net present value of the investment could rise by 44 percent to US$245 million. This considerable value of a global public good justifies exploring carbon finance to support CSA uptake and to compensate farmers for initial losses from CSA adoption.

Four CSA strategies—crop diversification, commercial horticulture, agroforestry and reducing post-harvest loss—show the greatest promise, perform well while reducing trade-offs between indicators, and should receive funding and institutional support. Despite potentially promising effects, CSA adoption rates remain low. In addition to factors associated with CSA practices, such as deferred benefits or high initial costs of adoption, the enabling environment in Zambia—specifically inadequate access to rural finance, capacity building and markets, but also insecure land tenure and distortionary public policies which tend to focus on maize production—present significant bottlenecks (see Table ES.3 for an overview of the enabling environment's impacts on the adoption of CSA practices). Considering household and sectoral indicators, as well as conditions in Zambia's enabling environment that support the adoption of CSA, the practices were ranked—showing that crop diversification, commercial horticulture, agroforestry, and reducing post-harvest loss seem most promising (see Table ES.4).

Public resources should be allocated to crowd-in private sector finance and maximize finance for achieving agriculture sectoral goals and realize agriculture's potential to contribute to Zambia's structural transformation. The analysis explores eight proven and innovative mechanisms and investment opportunities that can enhance CSA adoption. The mechanisms are ranked by their potential to address key constraints to CSA adoption, that is, inadequate access to rural finance, capacity building and markets:

(i) Business partnerships with rural communities, in which agribusinesses promote the adoption of sustainable land management practices, provide environmental certification and leverage carbon finance; thereby providing smallholders with capacity building, access to markets, and finance.

(ii) Outgrower schemes with small-scale irrigation to promote commercial horticulture production. and thereby provide farmers with improved access to markets and finance, training and services.

(iii) Participatory, integrated landscape management approaches to address multiple objectives of crop and livestock production, forest management, and environmental sustainability. Participatory elements favor knowledge exchange among rural communities and integrated land and water management practices enhance eligibility to participate in carbon finance projects.

(iv) Farmer field schools to enhance community-based learning and timely knowledge exchange, as well as facilitated market access through strengthening of farmer groups and associations.

(v) Pluralistic participatory extension approaches to enhance adoption of agricultural research and innovation, and spur private sector (*agri-preneurs* and agro-dealers) involvement in service delivery, to improve farmers' business skills and facilitate market linkages.

(vi) Weather index insurance schemes, which are combined with a mandatory adoption of CSA practices to enhance resilience to climate change and shocks. This scheme is expected to provide training and can be combined with savings schemes which facilitate access to finance.

(vii) Cash transfer programs can be aligned with agriculture sector programs and planting cycles, to provide farmers with access to capital to start-up climate-smart agriculture operation and enhance livelihood resilience.

(viii) Principles of gender-sensitive supply chains are applicable to each mechanism; gender-sensitive interventions may help overcome enabling environment constraints to support women to adopt CSA.

Adopting these delivery mechanisms (i)-(vi) and implementing them for approximately 800,000 Zambian farmers, that is, more than 50 percent of the country's smallholders, would require an annual public sector investment of US$32 million over five years. Delivery mechanisms have an indicative cost of US$15 million (weather index insurance) and up to US$59 million for participatory pluralistic extension approach which combines agricultural research and dissemination. If rolled out to 118,000 beneficiaries each, which reflects the current adoption rate of 8 percent of minimum soil disturbance in Zambia, expected rates of return on investment range from 11 percent (weather index insurance) to 39 percent (farmer field school). Only the participatory pluralistic extension approach

Table ES.3 Barriers to adoption of CSA practices in Zambia

	Land tenure systems	Capacity building	Access to finance	Access to rural infrastructure	Access to markets	Distortionary public policies
Conservation agriculture *(minimum soil disturbance, residue retention, rotation)* **Agroforestry**	🔴 Lack of secure tenure is a disincentive to adopt practices with deferred benefits	🔴 Deferred benefits pose a risk to farmers but this can be mitigated by adequate capacity building	🔴 Upfront costs (e.g., inputs, labor, mechanization) are found to impede adoption	🟢	🔴 Opportunities to generate income reduce risk of adopting new practices	🟡 Fertilizer subsidies may decrease economic rational for adoption; subsidy schemes could be paired with advisory services to enhance adoption.
Commercial horticulture	🟡 Horticulture has short cultivation cycle, and can be cultivated on small plots; insecure land titles could hinder investment in irrigation systems.	🔴 Diversifying into new crops requires access to advisory services	🔴 Access to finance critical as new inputs, infrastructure and transport are needed to set up operations	🔴 Irrigation, roads, and access to markets crucial for stable production and links to agri-businesses		🟡 Can lead to lower competition among input suppliers and traders as well as higher input costs
Livestock diversification	🟢 Mobile asset; grazing often occurs on communal land	🔴 Diversifying into new species requires access to advisory services incl. animal health	🟡 To start operation, access to finance critical; livestock serves as "savings bank"	🟢	🟡 Access to new species, and health services is a challenge	🟡 Current focus on maize impedes the production of crops to develop livestock feed industry
Timing of planting	No specific impact	🔴 Lack of advisory services affects planting decisions	🔴 Lack of inputs negatively affects timing of planting	🟡 Access to infrastructure facilitates delivery of inputs and reduces involuntary planting delays	🔴 Lack of input markets often causes planting delays	🔴 Late delivery of subsidies was found to affect timing of planting
Drought- and heat-tolerant seeds	🟡 Benefits accrue shortly after planting	🟡 No specific capacities compared to conventional practices	🔴 Improved seed usually costly, access needed to start operation	🟢	🟡 No specific difference from conventional practices, except supply of seeds.	🟢 FISP has facilitated access to improved maize seeds
Crop diversification	🟡 Research shows small land sizes disincentivize diversification	🔴 Access to advisory services a crucial driver of diversification	🔴 Access to finance critical new inputs needed to set up operation	🔴 Access to markets and irrigation supports diversification		🟡 Disincentivizes diversification; but ongoing reforms of FISP could reduce barriers
Reducing post-harvest loss	🟢	🟡 Access to advisory services can help reduce post-harvest losses on farm	🔴 Access to finance critical to get access to adequate technologies	🔴 Access to rural infrastructure includes storage facilities which are critical	🔴 Access to markets provides incentives to reduce post-harvest loss	🔴 Disincentivizes private sector involvement in storage and warehouse facilities

Source: World Bank, own elaboration

🟢 Low barriers to adoption 🟡 Medium barriers to adoption 🔴 High barriers to adoption

Table ES.4 Impacts of CSA practices on key decision variables

	Past household-level impact			Projected sector-level impact			Rural Development	Feasibility	
	Income	Reduce income variability	Food security	Crop yield	GHG mitigation	Food availability	Job creation & market linkages	Available funds	Enabling environment
Minimum soil disturbance	[Low-medium positive effect] **Wet conditions (–)** Long run positive; short run negative; strong geographic variation	[Negative effect]	[Low-medium positive effect] Crop yields increase, strong spatial variation	[Low-medium positive effect] **Climate change (–)** Strong increase under BAU; decrease under climate change	[Strong positive effect] **Climate change (++)** Enhances soil carbon sequestration	[Strong positive effect] **Climate change (++)** Contingent on adoption taking place in favorable areas	[Strong positive effect] Requires establishment of input markets (implements, inputs, mechanization)	[Strong positive effect]	[Negative effect]
Residue retention	[Strong positive effect] **Wet conditions (–)**	[Strong positive effect]	[Strong positive effect] **Dry conditions (+)**	[Negative effect] **Climate change (–)** Slight increase under BAU; negative under climate change	[Low-medium positive effect] **Climate change (–)** Increased fertilizer emissions; but soil carbon sequestration occurs	[Negative effect] **Climate change (–)**	[Low-medium positive effect] No notable impact	[Strong positive effect]	[Negative effect]
Crop rotation/ intercropping	[Strong positive effect] **Wet conditions (–)** Long run positive; short run neutral	[Low-medium positive effect] Strong geographic variation	[Low-medium positive effect] **Dry conditions (+)** Strong geographic variation	n/a	n/a	n/a	[Strong positive effect] Investment in legume value chain development and processing; access to new markets (traders, processors) creating job opportunities	[Strong positive effect]	[Negative effect]
Crop diversification (largely legumes)	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Strong positive effect]	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Strong positive effect] **Climate change (–)** Increases for most crops, though less under climate change	[Low-medium positive effect] **Climate change** Increased fertilizer emissions; but soil carbon sequestration occurs	n/a		[Low-medium positive effect]	[Low-medium positive effect] Ongoing reforms expected to lower barriers
Commercial horticulture	[Strong positive effect] **Dry conditions (+)**	[Strong positive effect]	[Strong positive effect]	n/a	n/a	n/a	[Strong positive effect] Access to new markets, processing and value addition	[Low-medium positive effect]	[Negative effect]
Agroforestry	[Low-medium positive effect] No effect in the short term	[Strong positive effect]	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Strong positive effect] **Climate change (–)** Increase is less under climate change	[Strong positive effect] **Climate change (–)** High levels of soil carbon sequestration and biomass growth	[Strong positive effect] **Climate change (++)**	[Low-medium positive effect] Low potential of value chain development (maybe nursery)	[Low-medium positive effect]	[Negative effect]
Livestock diversification	[Low-medium positive effect] **Wet conditions (–)** No significant impact; geographical variation	[Strong positive effect] **Dry conditions (+)**	[Strong positive effect] **Dry conditions (+)**	n/a	[Negative effect] Increase in livestock herds increases methane emissions	n/a	[Strong positive effect] Opportunities for veterinary services, trading, processing	[Low-medium positive effect]	[Low-medium positive effect] Ongoing policy reforms expected to lower barriers
Delayed planting	[Negative effect] **Dry conditions (–)** **Wet conditions (–)**	[Negative effect]	[Negative effect]	n/a	n/a	n/a	[Low-medium positive effect] Development of input markets and advisory services	[Low-medium positive effect]	[Negative effect]
Drought- and heat-tolerant seeds	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Strong positive effect] **Dry conditions (+)** **Wet conditions (+)**	[Low-medium positive effect] No notable increase under BAU; positive under climate change	[Low-medium positive effect] No change under BAU; climate change could equally increase/ decrease the effect on mitigation	[Low-medium positive effect] No change under BAU, positive effect under climate change	[Low-medium positive effect] Development of input markets can create jobs	[Low-medium positive effect]	[Low-medium positive effect] Moderate constraint
Reducing post-harvest loss	n/a	n/a	n/a	[Strong positive effect]	[Strong positive effect]	[Strong positive effect]	[Strong positive effect]	n/a	[Negative effect]

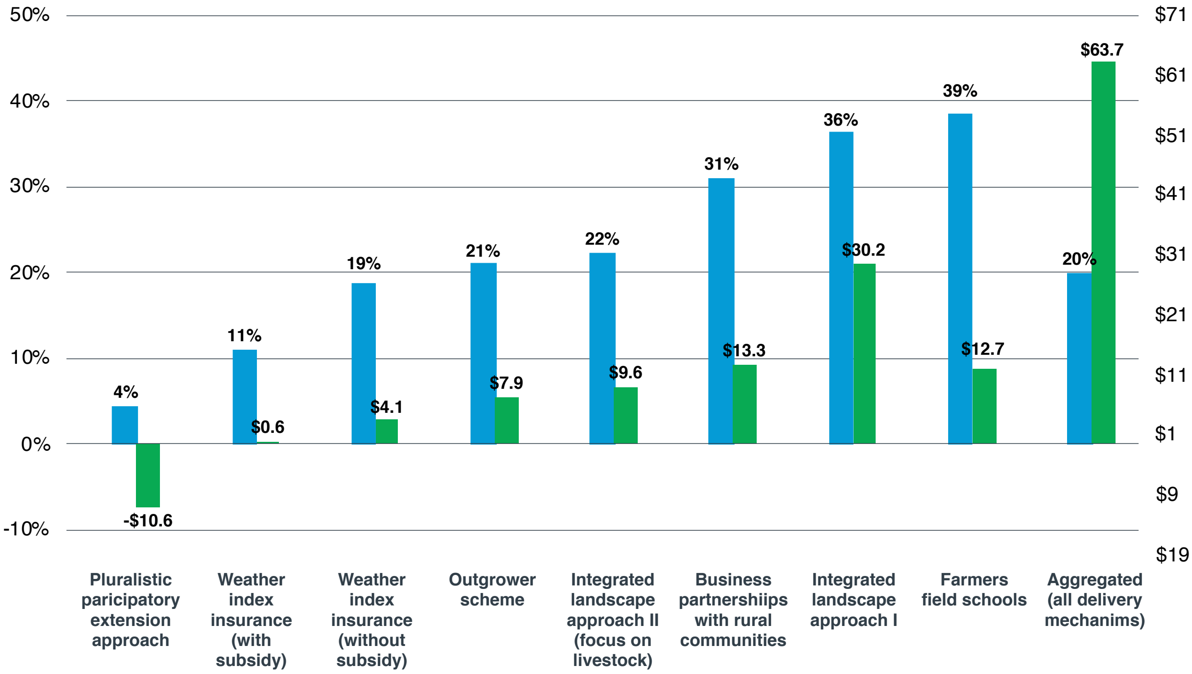
Source: World Bank, own elaboration

[Strong positive effect] Strong positive effect [Low-medium positive effect] Low-medium positive effect [Negative effect] Negative effect

Note. (i) Colors (green, yellow, red) indicate the impact of CSA practices on key indicators; (ii) Dry conditions/Wet conditions +/- indicates whether increased or decreased rain have a positive or negative effect on CSA's impact on the key indicator; (iii) Climate change ++/+/- corresponds to the error bars in GLOBIOM figures and indicates the magnitude and directionality of the range of effects that a CSA practice can have on indicators. It indicates whether the effect is strongly positive, or rather positive or negative under climate change projections.

would be below the opportunity cost of capital, with a 4.4 percent rate of return (see Figure ES.5). Overall, the rates of return of these delivery mechanisms are sizeable and should be considered when designing investment projects. A joint rollout of delivery mechanisms to more than 50 percent of farmers would yield a 20 percent rate of return on investment. The estimated annual investment requirements of US$32.6 million over 6 years is less than recent GoZ and donor funding for the agriculture sector. Thus, while investment quantity is necessary, the quality of delivery mechanism and targeting of investments to feasible and effective CSA practices is critical.

Figure ES.5 **Economic internal rate of return, in %, and net present value, in US$ million, of 7 delivery mechanisms, as well as aggregated**



Source: World Bank, own elaboration
Note: For each delivery mechanism economic indicators are calculated for approximatly 118,000 beneficiaries; aggregated this results in approximatly 826,000 beneficiaries

To support the scale up of climate-smart agriculture practices in Zambia, a combination of investment approaches and changes in the policy and enabling environment are needed. The CSAIP concludes with recommendations of climate-smart agriculture practices which appear most robust under climate change projections and are largely effective in achieving household welfare and agriculture sector goals through 2050: crop diversification, commercial horticulture, agroforestry and reducing post-harvest loss. All of which are constrained by, among others, inadequate access to finance and markets, and lack of capacity building and skills development. A range of investment bundles and delivery mechanisms can address these constraints. Business partnerships with rural communities, farmer field schools, and participatory integrated land management approach seem most favorable and have highest economic rates of return on investment. The findings of the quantitative analyses and assessment of investment options lead to eight policy recommendations (Box ES.1), ranked by feasibility and relevance, which can further support the effectiveness of proposed delivery mechanisms and thus a scale up of climate-smart agriculture practices in Zambia.

Box ES.1 Policy recommendations

The analyses of CSA practices under various scenarios and assessment of mechanisms to support CSA adoption show that **business partnerships with rural communities** which build on environmental sustainability as business strategy, **farmer field schools** to enhance community-based learning and technology dissemination, and **participatory integrated landscape management approaches** seem promising and profitable mechanisms to support the development of a productive, resilient, and low-emission agriculture sector. These can be supported by several policy actions:

1. Support farmers with **improved access to inputs and finance**, specifically in early stages of CSA adoption until benefits start to be realized. Support the development of markets for mechanization, innovative ICT-based solutions including agro-weather services for timely decision-making, and access to improved production inputs and seed varieties suitable for varied agroecological zones.

2. Support **agricultural research**, regional collaboration in research, participatory testing of CSA technologies to enhance their potential to increase crop yields, across and especially wet agroecological conditions. Support the advancement in the development and multiplication of seed varieties that are appropriate for rainfed production systems, in particular in the legume seed sector and short-duration maize seeds.

3. To increase agribusiness participation in the sector, **a range of policy actions** seem promising: (i) support feasibility, as well as risks and vulnerability assessments, to identify entry points and challenges; this should include an assessment of risk- and cost-sharing mechanisms which provide an understanding where the incentives align between the public good element of CSA and private sector motive; (ii) seek dialogue with agribusinesses about resulting investment opportunities; (iii) review the legal and regulatory framework to identify reform requirements and strengthen the business environment; (iv) provide opportunities for human capital development, capacity building and extension services for agriculture sector actors.

4. Support **operationalization of holistic landscape management approaches by harmonizing policies and supporting cross-ministerial collaboration** across the agriculture, environment, water and energy sector, and across administrative boundaries. Landscape approaches include climate-smart crop, livestock and forest management and have the potential to reduce alarming rates of land conversion for agriculture as well as addressing issues of biomass burning and charcoal production, which are key for Zambia's carbon footprint.

5. Pursue the **positive agriculture sector reform path of converting FISP into an e-voucher program, which supports agricultural diversification and adoption of short-duration varieties** targeted to Zambia's agroecological zones. The analysis shows the benefits of crop diversification into legumes, but also the need to improve the timing of planting or make short-duration varieties available to enhance crop yields.

6. Further support **development of market infrastructure such as rural storage facilities** and enable greater private investment in storage. Private investment may occur where production levels are high and stable and where access to border markets is feasible. In places where these conditions are not met, public investment may be required. In addition, training and collective action on improved post-harvest management bears a high potential to achieve CSA triple-benefits.

Section
1

Introduction

1.1 Agriculture Can Be Zambia's Engine of Structural Transformation and Growth

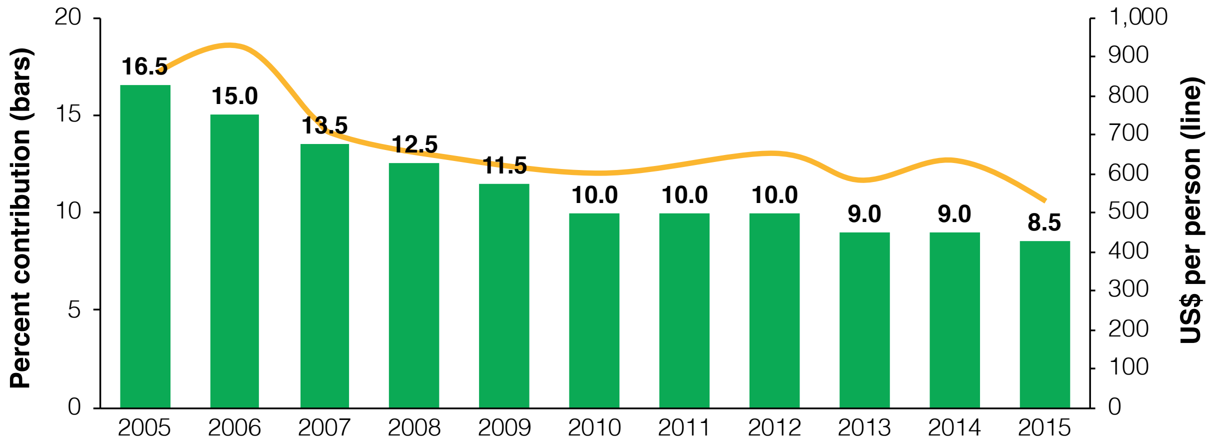
Zambia is a resource-rich, lower-middle-income economy that has successfully raised its average annual gross domestic product (GDP) growth rate since the early 2000s. Economic growth is heavily dependent on the minerals sector, and in particular on and changes in the international price of copper. Between 1985 and the 1990s, low levels of investment and production led to sluggish GDP growth, which rebounded between 2000 and 2014, when Zambia recorded economic growth of 7.4 percent per year; in the same period growth across sub-Saharan Africa averaged 5.8 percent. The country returned to middle-income status in 2011 as a result of improved economic management in the 1990s, a rebound in copper production, the expansion of the construction and services industries, and investment in the social sector by the government and cooperating partners (World Bank 2018e).

Despite increases in per-capita economic growth, poverty and inequality in Zambia have remained high, particularly in rural areas. The proportion of Zambians living on less than US$1.90 per day increased from 49.4 percent in 2002 to 64.4 percent in 2010 before declining once more to 57.5 percent in 2015. Over the same period, inequality as measured by the Gini coefficient increased from 0.42 in 2002 to 0.57 in 2015. Inequality is particularly apparent when comparing between rural and urban areas. As rural poverty rose from 73.6 percent in 2010 to 76.7 percent in 2015, urban poverty fell from 25.7 percent to 23.7 percent during the same period (CSO 2011 and 2016; World Bank 2018a).

The agricultural sector is the backbone of Zambia's rural economy and arguably the country's most important sector overall although it has been underperforming. Agriculture employs for 56 percent of the Zambian population, serves the critical function of buffering employment volatility in other sectors, and remains key to ensuring food and nutrition security particularly for financially vulnerable communities. While employment in the sector remains high, agriculture's contribution to GDP declined from 17.3 percent in 2004 to 5.3 percent in 2015, evidence that most Zambians remain locked into low-productivity subsistence agriculture characterized by a lack of access to key productive assets and market opportunities (World Bank 2018e). In fact, Zambia has among the world's highest rates of hunger and malnutrition, and although the incidence of stunting in Zambian children under five has declined from 45 percent in 2007 to 40 percent in 2015 it remains high (World Bank 2018e).

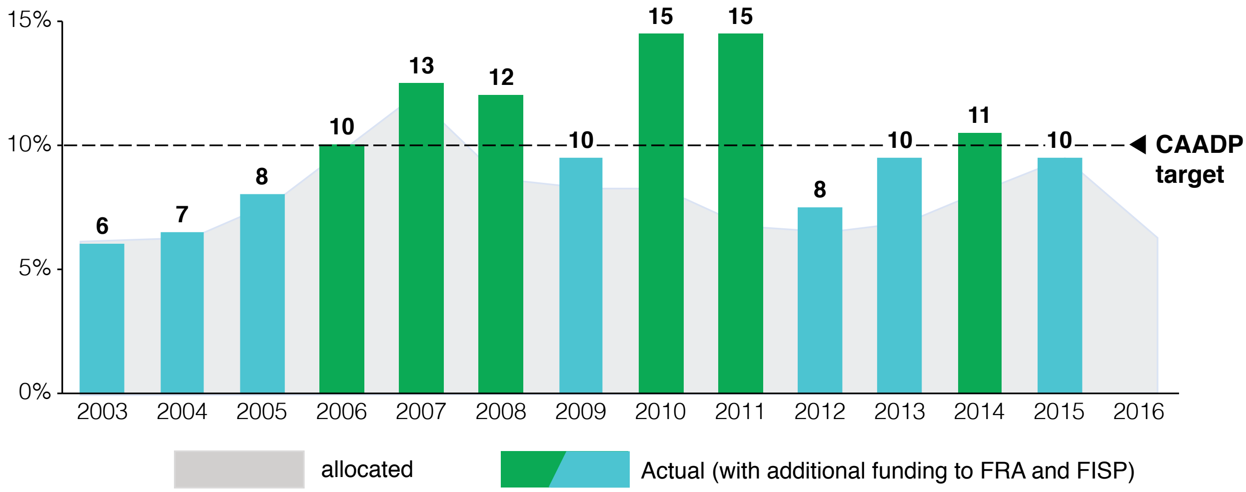
Declining agricultural labor productivity is an impediment to an effective structural transformation and poverty reduction in Zambia. If the decline in agriculture's contribution to Zambia's GDP were matched by an increase in agricultural labor productivity and a reallocation of labor toward the more productive manufacturing, specifically agro-processing, sectors, this could be taken as a sign of structural transformation and economic modernization. However, labor productivity as measured by value added per worker in the agriculture sector decreased from US$702 in 2004 to US$584 in 2015 (in constant 2010 US dollars; see Figure 1.1) and has not been accompanied by a significant increase in the labor participation in highly productive sectors. While segments of the rural labor force are moving out of agriculture toward wage employment in Lusaka, most workers move out of agriculture into other low-productivity sectors including the informal services sector or else remain smallholder farmers. This indicates that structural transformation is not being driven by the agricultural sector and is thus unlikely to be effective in reducing rural and urban poverty (World Bank 2018a; Merotto 2017).

Figure 1.1 Agriculture sector's contribution to GDP and value added per worker



Source: Chapoto and Chisanga (2016).

Figure 1.2 Agriculture sector spending and budget allocation as a share of total budget



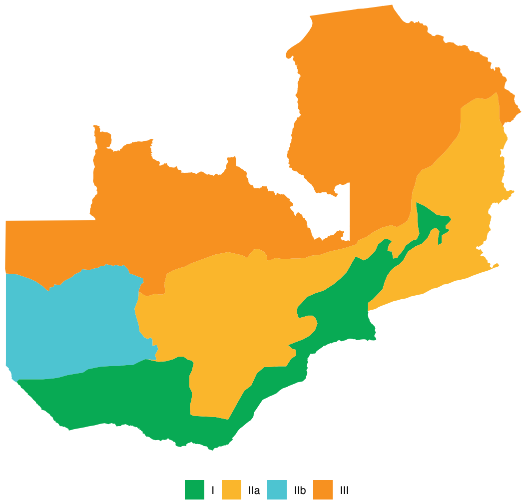
Source: Chapoto and Chisanga (2016).
Note: Bar charts include funding for FRA and FISP. Green bars indicate years in which CAADP targets were exceeded.

Low agricultural productivity is not necessarily the result of insufficient budget allocation and may instead reflect an ineffective use of funds. Poor agricultural productivity in Zambia can also be attributed to: limited access to land, water, and machinery; a lack of crop diversification; and low technology uptake (World Bank 2018e). Although the government subsidizes the agriculture sector, it has not notably succeeded in overcoming these constraints and reducing rural poverty. Since 2003, Zambia's budgetary allocation for agriculture has exceeded the 10 percent target set by the Comprehensive Africa Agriculture Development Programme (CAADP) six times (see Figure 1.2). Public expenditures include marketing support provided through the Food Reserve Agency (FRA) and input subsidies via the Farmer Input Support Program (FISP), which together accounted for an average of 79 percent of agricultural budgetary allocations between 2008 and 2016. Distribution of the agriculture budget has not sufficiently prioritized the investments needed to boost agricultural productivity growth and transform the sector (World Bank 2017a).

1.2 Agriculture Has a High Production Potential in Zambia

Zambia has three distinct agroecological zones (AEZs), which are distinguished by varying rainfall, temperatures, and soil types (see Figure 1.3). AEZ I, which covers most of the country's Southern and Western Provinces is a drought-prone area characterized by low rainfall (< 800 mm/year) and a short, hot growing season of 60–90 days. AEZ IIa and IIb cover much of Zambia's eastern, central, and western regions and have the country's highest agricultural potential with growing seasons of 90–150 days. AEZ IIa has slightly higher rainfall (800–1,000 mm/year) than AEZ IIb (600–800mm/year). AEZ III covers the northern regions of the country, with 1,000–1,500 mm of rainfall each year and the growing season lasts 140–200 days (Braimoh et al. 2018). Climate change and the effects of long-term processes of degradation are expected to alter the boundaries of the established AEZs through geographic shifting of crop suitability zones.

Figure 1.3 Zambia's agroecological zones

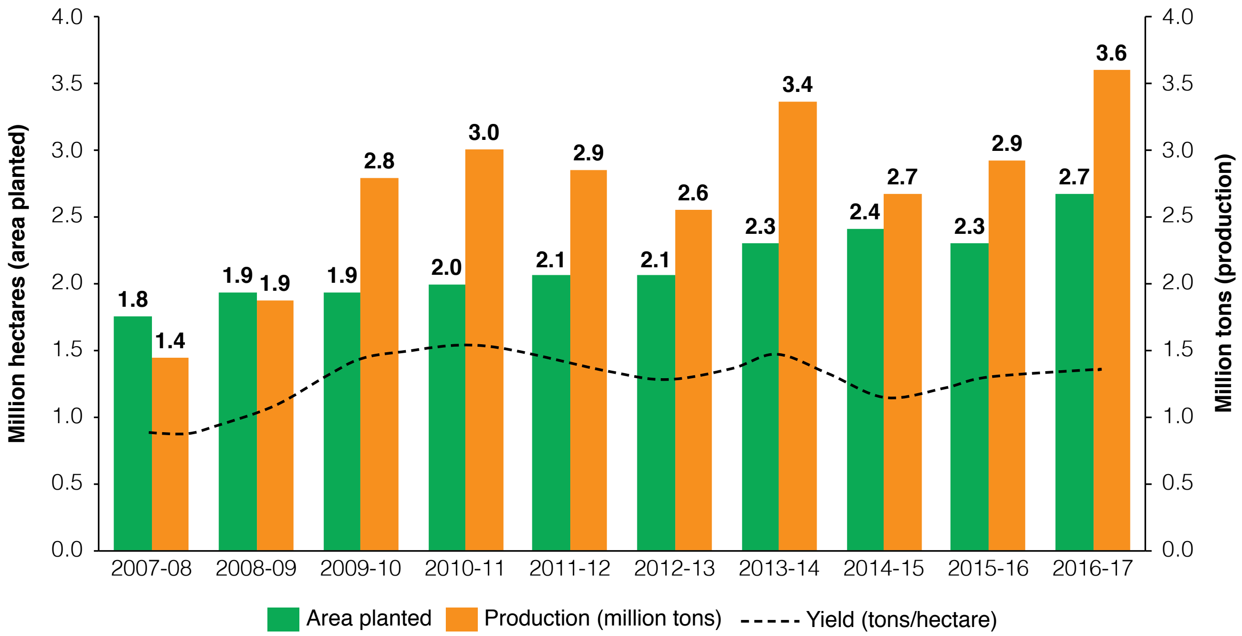


Source: Department of Meteorology, cited in Braimoh et al. (2018).

Zambia has generous endowment of natural resources. Despite high biophysical potential to diversify agricultural production, maize remains the dominant production system, covering approximately 2.7 million ha. Zambia has an estimated 74 million ha of land, of which 47 percent is classified as agricultural land, and 15 percent is currently under cultivation (GoZ 2016; GoZ 2017). In 2020, it is projected that there will be roughly 2.2 ha of arable land available for each Zambian (Samboko et al. 2017). Zambia has approximately 40 percent of the Southern Africa region's water resources. Although the country has 523,000 ha of irrigable land, only 155,890 ha, or 29 percent, are technically equipped for irrigation (GoZ 2017). Despite the potential for high productivity, about 90 percent of smallholders grow maize as their main crop, which covers about 57 percent of all arable land in Zambia. Tubers and cash crops account for around 18 percent across different farm sizes, and legumes occupy about 12 percent. About 70 percent of smallholder cultivate around three crops, of which 20 percent cultivate only one crops (Chapoto and Zulu-Mbata 2016; Arslan et al. 2018).

In addition to low agricultural diversification, there is a relatively high yield gap per hectare and by farm type and most production increases are the results of expansion of agricultural area. Farmers with small landholdings produce on average less than 2 MT of maize/ha/year, whereas the average maize yields for large-scale farmers (those with >20 ha of land) can exceed 5 MT/ha/year (CSO 2018; MoA 2016). Due to the low productivity, agricultural production increases stem mainly from land expansion (see Figure 1.4 on maize production). Agricultural expansion, together with deforestation for charcoal production, are the leading causes of Zambia's alarming deforestation rate—roughly 300,000 ha of forest are destroyed each year which is threatening the sustained provision of forest-related ecosystem services to the rural population (Wathum et al. 2016; Turpie et al. 2015). Nearly two-thirds of Zambia's forest area is on customary lands, and deforestation is generally attributed to charcoal production. This land is often converted to agricultural land once it has been cleared for charcoal (Turpie et al. 2015). Another study showed that in 2002 an estimated 90 percent of deforestation could be attributed to the clearing of land for agricultural production. Unsustainable practices like slash-and-burn hamper regeneration of land, and contribute to degradation and field abandonment, which forces farmers to expand further into forests for cultivation (Vinya et al. 2011).

Figure 1.4 Maize production and yields



Source: Central Statistical Office, cited in World Bank (2017a).

As domestic and regional food demand increases and diversifies, unprecedented opportunities are emerging for agriculture to become a driver of Zambia's economic growth. Several factors contribute to a high potential for increased agricultural growth. Firstly, domestic demand for a diversified diet is growing quickly in tandem with strong economic growth and the rise of an affluent urban population. Food demand is expected to triple over the next 15 years, and there is a visible dietary shift toward more processed products, vegetable oils and horticulture. Zambia already has a trade deficit in processed foods, dairy and fish even as imports of cereal, vegetables, and milling products are declining (World Bank, 2018a). This suggests increasing opportunities to substitute imports with domestic production. Secondly, Zambia is ideally situated to serve a growing regional market. It shares a direct border with seven neighboring countries, in which food demand is also expected to increase. Zambia, a net exporter in cereals, experienced export growth of 38 percent between 2003 and 2012, primarily of wheat (31 percent of cereal exports), maize (24 percent) and rice (15 percent) (Fessehaie et al. 2015).

To take advantage of these opportunities, the agricultural sector must raise productivity, diversify production and improve linkages to the agro-processing sector. Higher productivity, and diversification into higher-value horticulture and cash crops, would benefit household resilience by enabling farmers to produce more nutrient-dense food, gain access to diverse markets, and contribute to a more diversified and resilient economy (World Bank 2018d). Linking farmers to local and regional markets, value chains, and agribusiness will be crucial to unlocking the sector's potential. Strengthening the agribusiness sector can provide important upstream linkages to the agriculture sector, and represents a vital driver of productivity growth. Strengthening agribusiness will also enable the reallocation of labor and resources, provide additional income opportunities for rural populations, and enhance the effectiveness of Zambia's structural transformation (World Bank 2018a).

1.3 Zambia's Agriculture Sector is Vulnerable to Climate Change

While there is ample potential to strengthen Zambia's agriculture, the sector is likely to become more vulnerable to the effects of climate change and climate-induced risks. Over the last decades, climate variability and change have emerged as a growing threat to Zambia's sustainable development. Climate trends between indicate that the mean annual temperature increased by 1.3°C between 1960 and 2003, or an average of 0.34°C per decade. Mean rainfall has decreased by an average of 1.9 mm/month, or 2.3 percent each decade since 1960. Zambia has experienced a series of climatic extremes that include drought, seasonal and flash floods, extreme temperatures, and dry spells, many of these of increased frequency, intensity, and magnitude (GoZ 2015). Braimoh et al. (2018) suggest that between 1982 and 2016, droughts caused US$438 million in agriculture-sector losses; excessive rainfall and flood cost an additional US$172 million in losses. Between 2007 and 2016, climate change cost Zambia an estimated 0.4 percent or US$13.8 billion in annual GDP growth. Over the next 10–20 years, agricultural losses related to climate change are expected to reach US$2.2–3.1 billion, largely as results of waterlogged fields, water shortage, destruction of crops, and a higher incidence of crop and livestock diseases (World Bank 2018e).

Studies assessing the potential impact of climate change and weather events on Zambian agricultural indicators have returned mixed results. Jain (2007) estimates that farm revenue is negatively affected by higher mean temperatures in November–December and lower mean rainfall in January–February, but is positively affected by higher January–February mean temperatures. Thurlow et al. (2012), using a combination of a hydro-crop/dynamic computable equilibrium model, found that average maize yields can be expected to decrease by around 1 percent, except in western Zambia, where they are expected to increase slightly. Under more extreme climate scenarios, yield change is expected to be in the range of 4 percent to -6 percent. GDP is projected to decrease by -0.29 to -1.31 percent annually, and the poverty rate is expected to increase by between 1.69 and 7.23 percent, compared to a normal rainfall scenario.

Whether climate change has a net positive or negative impact on agriculture will depend on the province and the crop. Kanyanga et al. (2013) combine a crop model with the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to assess the impact of climate change on future food security in Zambia.[1] Crop growth simulations broadly indicate that maize yields may increase by more than 25 percent in Western Province, the eastern half of North-Western Province, Copperbelt Province, and most of Northern and Luapula Provinces. Whereas yields are likely to decrease by more than 25 percent in Southern Province and parts of Eastern Province. Overall, production is increasing while net exports of nearly all modeled crops are declining. Results from Kanyanga et al. (2013) suggest that climate change will result in a decrease in net trade for most agricultural commodities. Crop yields are projected to grow between 2020 and 2050 but at lower rates (CIAT and World Bank 2017).[2]

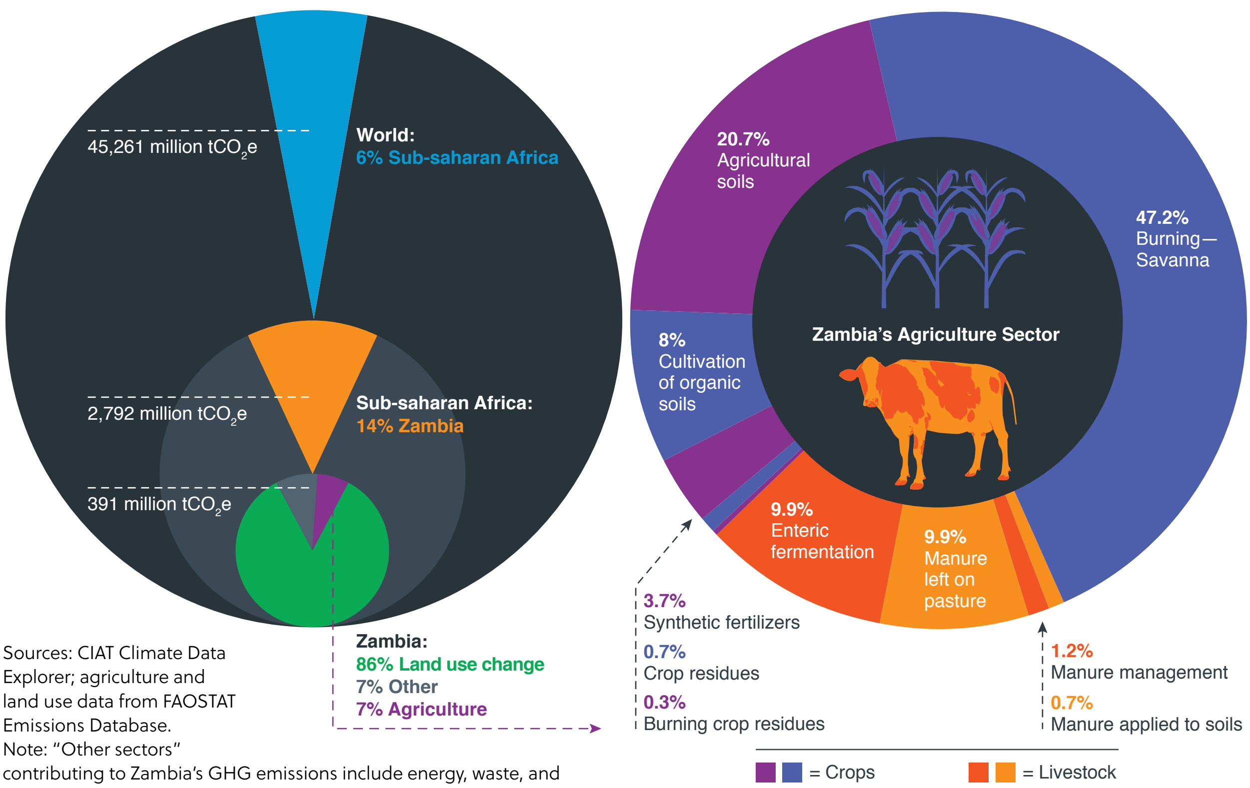
1.4 Land Use Change Is the Largest Contributor to Zambia's Carbon Footprint

While Zambian agriculture's carbon footprint is small on a global scale, the sector's contribution to total national emissions is sizable (see Figure 1.5). Adopting CSA practices is more important than ever because they offer potentially substantial climate change mitigation co-benefits. Zambia produces total GHG emissions of approximately 388 million tons of carbon dioxide equivalent ($MtCO_2e$) each year, which is about three-quarters of a percentage point of global GHG emissions. Within Zambia however, land use, land-use change and forestry (LULUCF) together with the agriculture sector accounts for 328 $MtCO_2e$ and 22 $MtCO_2e$ of emissions, respectively, or a combined 93.1 percent of Zambia's emissions. Energy accounts for approximately 6.5 percent, and is included in the category "other." Ninety-three percent of LULUCF emissions are caused by burning biomass; the remaining seven percent are produced during the conversion of forest to cropland or other land use. Within the agriculture sector, the burning of savanna contributes to 59 percent of emissions (including fire management, slash-and-burn cultivation, and encroachment), followed by emissions from enteric fermentation (13 percent), manure left on pasture and manure management (12 percent), cultivation of organic soils (10 percent), and the use of fertilizer (5 percent), according to CIAT and the World Bank (2017).

1.5 Climate-Smart Agriculture Aims to Address Climate Challenges but Adoption Rates Remain Low

Climate-smart agriculture (CSA) can bolster Zambia's agricultural sector against potentially detrimental impacts and increased vulnerability arising from climate change. CSA aims at increasing productivity and resilience, while decreasing the sector's greenhouse gas (GHG) footprint. CSA aims to better integrate agricultural development and climate responsiveness, while achieving food security and broader development goals. CSA initiatives sustainably increase productivity, enhance resilience, and reduce or remove GHG emissions. This requires strategic planning to address trade-offs and synergies between three pillars: productivity, resilience, and mitigation (FAO 2013). The technologies and practices that are considered climate-smart are diverse and vary across regions and production systems, thereby reflecting context-specificity or opportunities, constraints and vulnerabilities. A recent review finds that across 33 countries, five technology clusters account for almost 50 percent of CSA technologies, they include: water management, crop tolerance to stress, inter-cropping, organic inputs and conservation agriculture (Sova et al. 2018).

Figure 1.5 GHG emissions: Zambia's agriculture sector in perspective



Sources: CIAT Climate Data Explorer; agriculture and land use data from FAOSTAT Emissions Database.
Note: "Other sectors" contributing to Zambia's GHG emissions include energy, waste, and industrial processes. It seems to vary between 7 and 9%.

Despite acknowledgement of the need to address climate change adaptation and mitigation challenges, policy implementation and overall adoption of CSA in Zambia remains low. CSA is by no means a new concept in Zambia: in fact, numerous CSA practices have been tested across the country and the region. Yet although CSA practices such as minimum soil disturbance, crop rotation, and permanent soil cover and conservation agriculture have been promoted extensively in the country by donors, the GoZ, non-governmental organizations (NGOs), and civil society, adoption rates remain low. In fact, as much as 95 percent of farmers have adopted and then abandoned one or more CSA practices in some locations (Arslan et al. 2014). Among significant obstacles to higher rates of adoption and retention are that CSA practices tend to be laborious, and farmers have poor access to critical labor-saving equipment such as jab planters, direct seeders, and rippers, as well as limited knowledge and capacity. As CSA practices, particularly those regarding soil health, rarely provide immediate benefits, there is a risk that farmers adopt and then quickly abandon them (CIAT and World Bank 2017).

1.6 Climate Change Is Typically Factored into Agriculture Sector Policies and Strategies

The GoZ has demonstrated increased commitment to addressing climate change concerns through its policies and strategies. Zambia has developed various climate change-focused policies, strategies, and projects, including: the National Policy on Environment (GoZ 2007a); the National Climate Change Response Strategy (GoZ 2010); the National Strategy for Reducing Emissions from Deforestation and Forest Degradation (REDD +) (Matakala et al. 2015); the National Adaptation Programme of Action on Climate Change (GoZ 2007b); the Nationally Appropriate Mitigation Actions; and the National Climate Change Policy (GoZ 2017a). These initiatives are aligned with the Seventh National Development Plan (GoZ 2017b) and the Vision 2030 (GoZ 2006), to promote "[a] prosperous middle-income country by 2030." Both support the advancement of a low carbon and climate-resilient development pathway.

Zambia's Nationally Determined Contribution (NDC) to the 2015 Agreement on Climate Change (The Paris Agreement) is an ambitious goal of both climate change mitigation and adaptation initiatives. The NDC sets a target of reducing emissions by between 25 and 47 percent from a 2030 baseline, contingent on the availability of international funding sources. Total emissions reductions of 38 $MtCO_2e$ have been pledged, conditional on US$35 billion in international assistance. The NDC acknowledges that climate-smart agriculture offers a path to achieving this goal through reductions in fertilizer use and turning of soil, increased soil carbon sequestration, and enhanced biogas factories.

Government planning documents demonstrate that clear and consistent progress has been made in mainstreaming climate change considerations and CSA strategies into the relevant sectoral frameworks. Following revision of the National Policy on Environment (2007) and development of the National Climate Change Response Strategy (2010), specific reference to and elaboration of responsive climate change adaptation and mitigation actions have been incorporated into all of Zambia's major planning documents (see Table 1.1). The ongoing revision of several sectoral policies, including the second National Agricultural Policy (2016), Extension Strategy (2016), and Forestry Policy (2014), suggests that the mainstreaming of climate change and CSA extends to sectoral planning efforts. Other sector policies currently under revision, such as the Irrigation Policy, Land Policy, and Livestock Policy, are also expected to reflect a climate change focus (summaries of the relevant policies are included in Appendix A). Owing to the broad-based consultative processes used to develop and update these policy documents, which involved all levels of government as well as outside stakeholders, mainstreaming efforts can be expected to extend well beyond the responsible ministries.

Table 1.1 The mainstreaming of climate change and CSA considerations within government policies

	Climate Change	Adaptation	Mitigation	CSA
Vision 2030 (2006)				
National Policy on Environment (2007)	✓			
National Adaptation Programme of Action on Climate Change (2007)	✓	✓		
National Climate Change Response Strategy (2010)	✓	✓	✓	
National Agriculture Investment Plan (2013)	✓	✓	✓	✓
Nationally Determined Contributions on Climate Change (2015)	✓	✓	✓	✓
National Disaster Management Policy (2015)	✓	✓		
Reduced Emissions from Deforestation and Forest Degradation (REDD+)(2015)	✓	✓	✓	✓
National Policy on Climate Change (2016)	✓	✓	✓	✓
Second National Agriculture Policy (2016)	✓	✓	✓	✓
Seventh National Development Plan (2017)	✓	✓	✓	✓
Climate-Smart Agriculture Strategy Framework (forthcoming)	✓	✓	✓	✓

The finalization of a national-level Climate-Smart Agriculture Strategy Framework establishes priorities and mechanisms to strengthen CSA initiatives across the country. The strategy paper, which is being prepared under the leadership of the Ministry of Agriculture, identifies several steps to enable scale-up of CSA: (i) develop an institutional mechanism and strategic operational framework that permits effective coordination and communication among CSA stakeholders; (ii) identify CSA approaches and practices that are responsive to climate change and can attract the required budgetary support; and (iii) strengthen mechanisms for dissemination of information, knowledge, and skills about appropriate CSA practices. The paper underscores that support for scaling up CSA is predicated on assessment and communication of the local and national benefits of CSA investments (including food security and global environmental benefits), specifically the "Development and utilization of evidence to help identify [CSA] investments specific to the locally present climate change, agricultural production and institutional conditions, focus on barriers to implementation and means of overcoming them, and building local institutional and policy frameworks to support the needed transformation" (unpublished draft, page 55).

It will be essential to monitor gaps in the implementation cycle to ensure that CSA-related actions are integrated into the appropriate planning documents and ultimately implemented in the field. Primary concerns include: (i) to ensure that the formulated implementation plans respond to observed weather-related stressors affecting different locations across the country; (ii) to allocate sufficient funding from domestic and external sources to support implementation; (iii) to establish a means of directing funds to critical activities and locations and tracking how these funds are ultimately used; and (iv) to ensure that facilities and trained personnel necessary to effectively carry out the planned activities are in place.

1.7 Objectives of the Zambia Climate-Smart Agriculture Investment Plan

The overarching goals of the Climate-Smart Agriculture Investment Plans (CSAIP) are "to identify and prioritize key policy actions, investments and knowledge gaps" and build on existing policies, strategies, and lessons learned through engagement with the agriculture sector to assess how CSA investment can strengthen climate change adaptation and mitigation initiatives and prioritize investments that promise cost-effective CSA approaches to achieving overall sector goals. The Zambia CSAIP is one element of the World Bank's corporate commitments to develop ten CSAIPs made during the Eighteenth Replenishment of the International Development Association (IDA18).

The CSAIP responds to the GoZ's needs that are highlighted in the Climate-Smart Agriculture Strategy Framework, and aims to inform the development of a second National Agriculture Investment Plan (NAIP). The CSAIP provides evidence of the local and national benefits and impact of CSA, assesses and prioritize climate-smart interventions, and identifies opportunities to invest in CSA and provides an indicative costing and economic analysis of these opportunities. In addition to informing development of a second NAIP, which will cover the 2022–2026 period, the CSAIP will also inform implementation of Zambia's Seventh National Development Plan. Unlike the first NAIP, the second one is expected to explicitly address climate change challenges and climate-smart agriculture. The CSAIP will provide quantitative data on the benefits of CSA under climate change, suggest investment opportunities and an indicative costing; however, the CSAIP will not provide a detailed investment plan to replace the NAIP.

To achieve these goals, the development of the CSAIP was guided by a set of questions. See Table 1.2 for an overview of these questions and approaches for addressing them.

The World Bank is demonstrating commitment to support and promote CSA strategies through implementation of analytical and operational projects as well as through the Zambia Country Partnership Framework (CPF). The CSAIP supports this agenda. Through Focus area I, the CPF promotes a more even territorial development by supporting opportunities and jobs for the rural poor. It aims to support sustainable, competitive, and diversified agro-food production as well as increased resilience to hydrological, climate and environmental shocks. Thus, the adoption of improved and climate-smart technologies, which is integral to the Zambia CSAIP, plays a critcial role. Besides the CPF's objectives, there are ongoing or recently completed projects aimed at strengthening CSA, improving landscape management, and providing benefits for rural communities. These include: the Zambia Integrated Forest Landscape Project in Eastern Province; the Strengthening Climate Resilience Project; and two analytical knowledge products: "Productive Diversification in African Agriculture and Impacts on Resilience and Nutrition" (Kray et al. 2018) and "Increasing Agricultural Growth and Resilience through Better Risk Management in Zambia" (Braimoh et al. 2018). The Zambia CSAIP builds on existing work and, by pointing out knowledge gaps, aims to inform future analytical and operational work.

1.8 Report Structure

The report is organized as follows:

- **Section 2—Methodology** introduces the overarching methodological approach of CSAIPs in general as well as the specific quantitative and qualitative approaches that were used with respect to the Zambia CSAIP.
- **Section 3—State of CSA adoption and performance in Zambia** provides a brief literature review for eleven CSA practices which are subsequently analyzed.
- **Section 4—Analysis Results: Observed impacts of CSA on households** summarizes findings from econometric assessments of the effects of CSA implementation on household-level welfare indicators. The section also presents the impact sensitivities of high weather variability (a proxy for

Table 1.2 Summary of CSAIP guiding questions and key approaches

Guiding questions	Overview of approach as employed in the report
Sector vision and policy relevance: How should the sector look in the future? What are the policy goals? • What are the quantifiable targets to achieve the sector vision, and which agricultural strategies are recommended to support these goals? • What are the key trends and uncertainties confronting the sector?	**Stakeholder workshops** held in Lusaka in October 2017 and April 2018 **Policy analysis and contextualization:** Identification of agriculture sector goals, targets (for example., as outlined in the Country CSA Program and NDC), and challenges; selection of potential CSA practices through (a) extensive reviews of policy documents and literature and (b) stakeholder consultations at several stages of the process
Potential impacts on households: Do households have sufficient incentives to adopt CSA strategies? • Which CSA strategies are promising and what are their projected impacts on key variables that are proxies for household welfare, such as household income and variability, food security, and poverty? • What is the financial viability of CSA strategies for households? • Which CSA strategies are robust in light of weather and climate variability? • How does the suitability of CSA strategies vary across Zambia's AEZs?	**Empirical assessments** of observed impacts of CSA: • Cost-benefit analysis at the household level to assess financial viability • Econometric analysis to evaluate the impact of CSA practices on household-level welfare indicators **Literature review and expert consultation** to contextualize and validate findings
Potential impacts at the sectoral level: Do CSA practices have an advantage to deliver key agriculture sector indicators compared to conventional practices, and are benefits robust across all climate change scenarios? • What is the CSA strategies aggregate effect on Zambia's agriculture sector and key variables, for example, production, mitigation, land use change, trade—in a future with and without climate change? • How do CSA strategies support the achievement of the agriculture sector vision and intermediate targets, also under climate change scenarios? • Is there an economic rationale to support CSA scale up?	**Agriculture sector model GLOBIOM:** Integrative quantitative agriculture sector modeling to assess the robustness of selected CSA practices against climate change in different regions of the country **Cost-benefit analysis at the sector level:** To assess economic profitability of supporting CSA adoption with public sector funds
Prioritization: To which CSA practices should financial resources and institutional capacity be earmarked? • Which CSA strategies have proven promising at the household and sectoral levels and should receive particular attention from the government and donor community?	**Prioritization:** Conduct a prioritization and ranking of candidate strategies based on their likely impact and feasibility.
Delivery: What is required with respect to public sector financing and innovative delivery mechanisms to ensure the adoption of CSA? • Which factors in the enabling environment are critical to achieve adoption of CSA? • What are innovative implementation arrangements that can support the adoption of prioritized CSA practices in Zambia? • Which CSA strategies have previously received financing and what are expected expenditures needed to enhance their adoption?	**Literature review and expert consultation** to elaborate constraints in the enabling environment and key delivery mechanisms to support the CSA scale-up **Expert consultation:** Assessment of current and necessary public sector funding to scale up CSA and achieve agriculture sector goals

climate change impacts) based on household survey data. The section also presents results of an analysis of the financial viability of adopting certain CSA practices at a household level.

- **Section 5—Analysis Results: Projected impacts of CSA on agriculture sector performance under climate change** presents the results of the GLOBIOM model, which assesses the impacts of adopting CSA practices through 2050 compared to conventional practices in a future with and without climate change. The impact is assessed on several agriculture sector indicators, which approximate the CSA areas of productivity, resilience and mitigation.

- **Section 6—Prioritizing CSA practices** ranks CSA practices according to their performance on household and sectoral level.
- **Section 7—Enabling Environment, Investment Options, and Financing to Promote CSA Adoption** discusses several dimensions of the enabling environment that facilitate and support the adoption of climate-smart technologies and practices; presents a summary of eight proven and innovative mechanisms that could support adoption of CSA; and provides the results of an economic analysis of each mechanism including an assessment of total investment needs.
- **Section 8—**presents the report's conclusions and recommendations.

Section

2

Methodology

2.1 The CSAIP Approach: A Flexible Framework

The CSAIP approach proposes a flexible framework to support countries' agriculture sector planning in the face of climate-related uncertainty. CSAIP incorporates quantitative modeling and analyses, stakeholder engagement, expert interviews, and a literature review, and comprised four key steps that can be tailored to fit a country's context (see Figure 2.1):

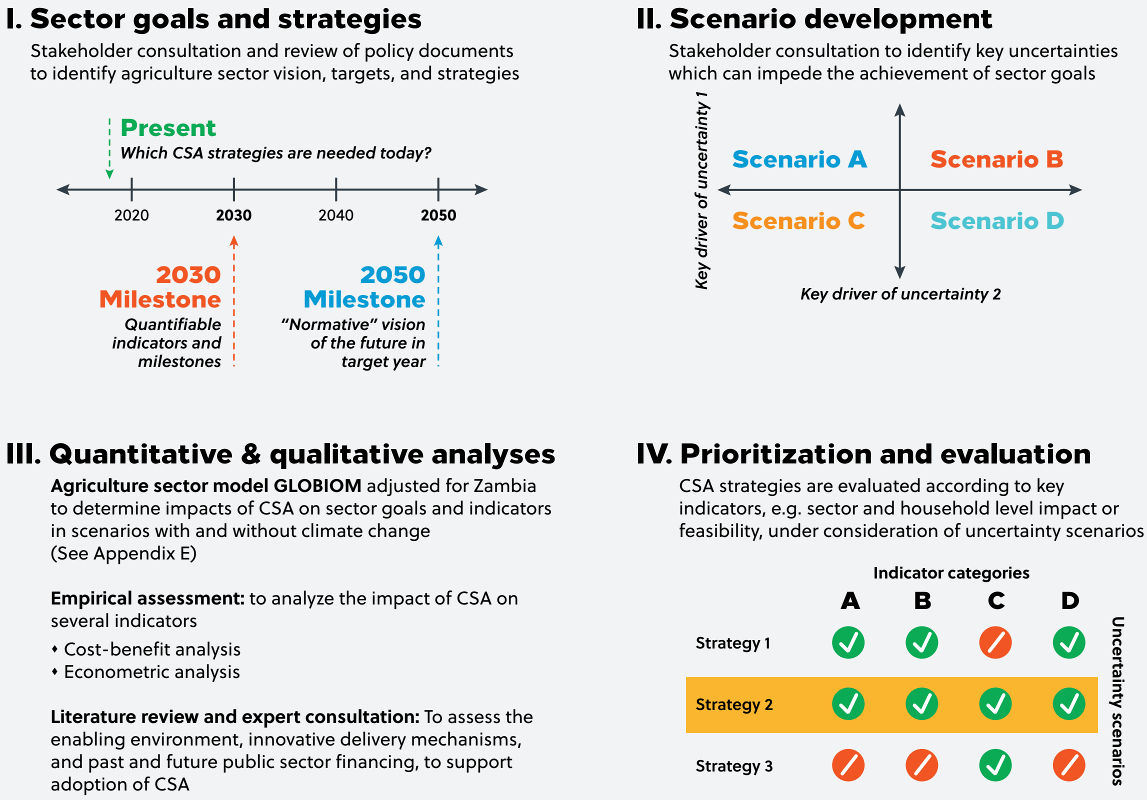
- **Step 1: Identify agriculture sector goals, targets, and strategies (see Section 2.2).** A collaborative, stakeholder-driven process took place to identify visions, goals, and strategies and to prioritize a handful of promising climate-smart technologies for Zambia's agriculture sector. As part of this process, a target year was determined, and sector goals or a "normative vision" of the sector developed that factors in national development plans, climate commitments, and ambitions for that year. Working backward from this normative vision, intermediate sector targets and priority strategies were identified that connected the normative vision with the present.

- **Step 2: Identify key uncertainties and known trends (see Section 2.2).** The second step of the stakeholder-driven process entailed developing key uncertainties and known trends into a set of potential alternatives, plausible futures, and scenarios.

- **Step 3: Perform quantitative and qualitative analyses (see Section 2.3–2.5).** These analyses projected the scale of potential impact that CSA technologies could have on achievement of sectoral goals and key socioeconomic and environmental variables in a future with and without climate change. This enabled the assessment of CSA technologies' desirability at the household and sectoral level. In Zambia, this step combined three quantitative approaches—an agriculture-sector model; cost-benefit analyses (CBA); and an econometric analysis to assess household-level impacts—with qualitative analyses of the enabling environment and of potential delivery mechanisms to support CSA adoption as well as past and future public-sector financing needs. See Table 1.2 for the guiding questions for Step 3.

Step 4: Prioritize and evaluate CSA strategies according to quantifiable indicators and key uncertainties. Based on this assessment, investment opportunities were identified which are innovative or have proven successful in scaling up adoption of certain CSA practices.

Figure 2.1 Integration of qualitative and quantitative approaches into CSAIP



Source: World Bank

2.2 Stakeholder Consultations to Determine a Vision, Goals, and Uncertainties for the Agriculture Sector

A vision for the agriculture sector was identified through a combination of policy review and stakeholder engagement. As a first step, the team conducted a comprehensive literature and policy review, and gathered and analyzed available data on Zambia's agriculture sector and climate change situation. Specifically, the analysis looked at whether and how sector policy and planning frameworks that were in effect between 2005 and 2017 planned to address challenges and opportunities to achieve the three CSA pillars of productivity, resilience, and mitigation. During a technical stakeholder workshop held in Lusaka in October 2017, participants, including ministerial officials, NGOs, think tanks and international organizations (see Appendix H for a full list), jointly reviewed existing national and agricultural planning reports and formulated a normative vision for the development of Zambia's agriculture sector (see Table 2.1).

As a next step, measurable targets were identified to assess whether and to what extent CSA practices might contribute to the agriculture sector vision. Participants identified and prioritized measurable sector targets across the three CSA pillars that would be critical to achieving the vision. See Table 2.2. for an overview of measurable targets and indication whether and how CSAIP models address the target, and which CSA objectives are being addressed (see Appendix A for a detailed overview of relevant policy documents, as well as the sector vision and quantifiable targets where available).

In addition, a number of promising CSA strategies were identified that offer the potential to achieve specific intermediate goals and, ultimately, the normative vision for the agriculture sector (see Appendix B for strategies identified during the 2017 technical stakeholder workshop). Following the workshop, a number of CSA strategies were chosen as priorities through an iterative process that involved key technical focal points from Zambia's Ministry of Agriculture. Table 2.3. presents those practices, as well as the quantitative approaches used to analyze them. Due to data constraints, not all practices could be analyzed with each method.

Table 2.1 Normative vision for Zambia's agriculture sector developed during the stakeholder workshop

Source	Normative vision as developed in stakeholder workshop	CSAIP modeling targets(a)	CSA pillars
Stakeholder workshop	By 2050, double yields and profits by means of diversification (beyond maize), while ensuring household food and nutrition security	Doubling of crop yields compared to baseline (2009-2011 average)	Productivity
Stakeholder workshop	By 2050, develop an agriculture sector that is (i) diversified in crop production, (ii) diversified in age and gender, and (iii) able to cope with economic and climatic shocks through enhanced capacity and policy	No target; assessment of impact of crop diversification scenario on key agriculture sector indicators	Resilience
Stakeholder workshop	By 2050, increase the productivity of Zambia's agricultural sector while maintaining a low ecological footprint	25-47% decrease in GHG emissions in comparison to BAU scenario	Mitigation

Note: (a) For the modeling approach, the quantifiable targets as stated in policy documents and by stakeholders, were approximated based on data and information availability. For the normative vision of diversifying crop production no quantifiable target was available.

Table 2.2 Quantifiable targets for achieving the long-term vision for Zambia's agriculture sector

Policy	Quantifiable targets to achieve the long-term vision	CSAIP modeling targets(a)	CSA pillars
Seventh National Development Plan (2017)	Raise agriculture's share of the GDP by 10% by 2021	N/A	Productivity
	Raise the value of agriculture, livestock, and fishery exports to US$931 million, or 7.8% of total export value, by 2021	N/A	Productivity
National Agriculture Investment Plan (2014–2018)	Increase the share of agricultural exports as a percentage of non-traditional exports from 41% in 2011 to 55% by 2018	Doubling of net crop exports compared to base year 2010	Productivity
	Increase production of cereals from 3.2 million MT to 6.0 million MT	Achieve total production of 6 million MT	Productivity
National Long Term Vision 2030 (2006)	Increase land under cultivation by 900,000 hectares by 2030	Cropland increase < 900,000 ha (average 2000-2013 as baseline)	Productivity
	Increase livestock population to 6,000,000 animals by 2030	6 million cattle, double number of small ruminants (average of 2012-2014 as baseline)	Productivity, Resilience
National Policy on Environment (2007)	Sustainably intensify land use without converting additional land area to agricultural land	Sum of cropland and grassland do not increase (average of 2000-2013 as baseline)	Resilience, Mitigation
Nationally Determined Contribution (2015)	Reduce GHG emissions by 25% with limited international support or 47% conditional on the receipt of US$35 billion of international assistance	% decrease (25-47%) in GHG emissions by emission category compared to business-as-usual scenario in 2050[4]	Mitigation

Note: (a) For the modeling approach, the quantifiable targets as stated in policy documents and by stakeholders were approximated based on data and information availability. Some targets could not be modeled (n/a).

Table 2.3 CSA practices incorporated into the analysis and overview of quantitative assessments

	Household level		Sector level	
		Cost-Benefit Analysis:		
CSA Practice	Econometric analysis	Financial analysis	Economic analysis	GLOBIOM
Conservation agriculture's 3 pillars:				✓
Minimum soil disturbance	✓	✓	✓	✓
Residue retention	✓	✓	✓	✓
Legume rotation / intercropping	✓	✓	✓	✓
Agroforestry	✓	✓	✓	✓
Commercial horticulture	✓			
Crop diversification	✓			✓
Livestock diversification	✓			
Drought-tolerant seeds	✓			✓
Timing of planting	✓			
Agricultural liming[a]	✓			
Reducing post-harvest loss				✓

Note: (a) A statistical analysis is performed for agricultural liming due to data unavailability.

Lastly, workshop participants identified a range of factors that could harm the agriculture sector and impede achievement of its goals. These factors were categorized as either climate change-related or socioeconomic uncertainties, and were used to design scenarios for projections with the modeling framework. The first results of the analysis were presented and discussed during a subsequent stakeholder workshop in April 2018.

2.3 Econometric Analysis to Determine CSA Impacts on Welfare of Zambian Households

An econometric assessment enabled the estimation of CSA strategies' impact on a range of welfare indicators. The analysis provided responses to a number of key questions: (i) What are the potential impacts of adopting CSA on key CSA variables and on household welfare, for example, household income and variability, food security, and poverty? (ii) Which strategies are robust in the light of weather variability? Which CSA strategies are suited to the specific AEZs in Zambia? See Table 2.4 for an explanation of the six welfare indicators. Also, see Appendix C for more details.

Two econometric approaches were used to assess the impacts of adoption of CSA practices on key welfare outcomes. The first approach incorporated a difference in difference (DiD) estimator to assess the impacts CSA adoption had on several welfare variables (see Table 2.4), and provided an estimate of the direct causal impact of CSA adoption. However, one limitation of the approach is that the sample of adopters is restricted to only recent adopters, that is, those that adopted CSA between the 2012 and 2015 household surveys. This represents a significant constraint because the benefits of some CSA approaches are not immediate. Therefore, a second approach was used to complement the first: CSA adopters were classified as households that adopted the practice in the 2012 and 2015 surveys. The impacts of CSA adoption were then estimated using an Ordinary Least Squares (OLS) approach. A drawback of this second approach is that it fails to control for selection bias, which raises concerns about endogeneity. Accordingly, results from the second approach are interpreted as conditional correlations rather than causal impacts.

Table 2.4 Outcome indicators of the welfare analysis

Indicator	Definition
Gross crop income	Sum of the value of all crops produced, including crops sold and crops retained for consumption; crop prices are estimated based on the average farm-gate prices at a district level
Crop income variability	The coefficient of variation of gross crop income
Gross income	Sum of all income sources, including off-farm sources and the value of retained agricultural production
Income variability	The coefficient of variation of gross household income
Poverty	Per capita net income of less than US$1.25 a day in real 2010 US dollars
Food insecurity	Negative response to the survey question "did the household have sufficient food to meet household food security needs in agricultural season 2013/14"

The econometric analysis is based on the Rural Agricultural Livelihoods Surveys (RALS) household survey. RALS is a nationally representative survey of Zambia's smallholder households that cultivated fewer than 20 ha in 2012 and 2015 (CSO et al. 2012 and 2015). The survey contains georeferenced information on sociodemographic characteristics, farm management practices, access to credit and assets, access to markets and infrastructure, information availability, inputs used, and outputs produced. The survey comprised 7,254 households in 2012 and 7,934 households in 2015.

To assess the performance of CSA practices under weather variability, the Standard Precipitation Index (SPI) was added to the econometric analyses. Extremely low and extremely high rainfall approximate climate sensitivity. The SPI was developed primarily to define and monitor drought, and can also be used for flood identification. SPI can be used to determine the probability of drought at a given point in time for any rainfall station with historic data. All econometric models were re-estimated using combinations of the SPI between a certain threshold to capture extreme dry and extreme wet periods. Thus, the estimation results provide an indication whether specific CSA practices are more effective under very dry or wet conditions, which approximates climate sensitivity.

2.4 Cost-Benefit Analysis to Determine Financial and Economic Profitability of CSA

The cost-benefit analysis (CBA) includes a financial and economic analysis to determine the profitability of adopting CSA at the household and sectoral level. The analysis provides answers to two guiding questions: (i) What is the financial viability of CSA practices for a household? (ii) How do the anticipated costs needed to scale up CSA compare to the anticipated economic benefits? First, a financial analysis was undertaken to determine financial viability and incentives for an average household to adopt CSA in several AEZs. This was done by assessing the net incremental benefits accruing to a household following the adoption of CSA practices as compared to keeping conventional farming practices. Second, an economic analysis was used to assess the economic and societal benefits of adopting CSA, and to determine whether there was an economic rationale for the public sector to support widespread adoption by farmers of CSA. This served to answer the underlying question of whether public sector financing is warranted to support the adoption of CSA. See Table 2.5 for resulting indicators; see also Appendix D for details.

The financial analysis is based on a unique household data set on CSA adoption as well as the RALS survey. FAO collected the CSA-specific household data, which provides information for 695 households about crop yields, income, and production costs associated with adoption of CSA practices in the 2012–13 cropping season. The households were determined according to a stratified random sampling technique, and data about crop production was reported at field level (that is, 1,264 fields in AEZ IIa and III). Among other data, the dataset included information on cropland use, input quantities and cost, labor use in different management activities, and household demographic characteristics. This survey covers selected CSA practices in several AEZs, which was complemented by findings from the RALS household survey.

Additional variables were incorporated into the economic analysis: economic benefits for households adopting CSA, public good benefits accruing from climate mitigation, and expected public sector investments. For the economic analysis, households' financial net incremental benefits were evaluated at economic prices and aggregated across the projected number of CSA adopters. The Ex-Ante Carbon Balance Tool (EX-ACT) was used to assess public good benefits arising from CSA's climate mitigation potential. EX-ACT enables calculation of the net carbon balance, that is, the difference between gross emissions under conventional practices and gross emissions under CSA practices (see Table 2.5). To quantify the value of climate mitigation, the net carbon balance is valued at a shadow price of carbon that was calculated based on the concept of marginal abatement cost.[5] The shadow price of carbon indicates the carbon price which is consistent with achieving the core objective of the Paris Agreement on climate change (2015) of keeping temperature rise below 2 degrees. To assess the public expenditure needed to support CSA adoption at the sectoral level, information was sourced from previous Zambian investment projects, gray literature and personal interviews with government institutions, independent research entities and NGOs, and international institutions.

The economic analysis was performed for two adoption scenarios. Scenario one: 8 percent of farmers adopt CSA, which, according to the RALS survey, reflects the current adoption rate for minimum soil disturbance. This is equivalent to 118,000 households, or 6.4 percent of households in AEZ I; 13.9 percent of households in AEZ IIIa; 1.1 percent in AEZ IIb households; and 4.7 percent of households in AEZ III. On average, households cultivate 1.71 ha. Scenario two: 50 percent of farmers adopt CSA. An adoption rate of 50 percent for minimum soil disturbance was discussed during the 2017 stakeholder workshop. It can be considered as aspirational target for 2050.

Table 2.5 Outcome indicators of the cost-benefits analysis

Indicator	Definition
Financial analysis	
Gross margins	Gross margins represent total revenues from crop production minus total production or variable costs excluding labor
Net margins	Net margins are calculated as the gross margins, but factor labor costs into total production costs
Net incremental benefits of adoption	This represents the expected financial returns for households generated by the adoption of CSA activities as compared to conventional farming methods.
Economic analysis	
Net carbon balance	The net carbon balance is the difference between GHG gross fluxes under CSA adoption and under conventional farming practices. Results are given in tons CO_2 equivalent (tCO_2e). Positive numbers represent sources of CO_2e emission while negative numbers represent a carbon sinks. This is valued at a shadow price of carbon and included in the economic analysis as public good benefits. The value is assessed with EX-ACT.
Net present value (NPV)	The NPV is the difference between the present (discounted) value of cash inflows and the present value of cash outflows over a period of time.
Economic internal rate of return (EIRR)	The EIRR is the discount rate at which the calculated NPV equals zero. A high EIRR provides confidence in the profitability of an investment.

The robustness of the economic benefits is determined through a sensitivity analysis incorporating variations of key variables. The sensitivity analysis considers the performance of the investment options under different scenarios, including changes in the flow of benefits and costs, changes in the adoption rate, and changes in crop yields.

2.5 GLOBIOM Approach Used to Assess Agriculture Sector Goals

GLOBIOM is an integrated modeling approach developed by IIASA that enables joint analysis of the agriculture, forestry, and bioenergy sector. GLOBIOM is a spatially explicit partial equilibrium model of the global forestry and agricultural sectors (Havlík et al. 2014) used to analyze the competition for land use between the main land-based production sectors: agriculture, forestry, and bioenergy. GLOBIOM enables assessment of the aggregate effects of CSA technologies on key agricultural sector variables; agricultural and land use change and trade-offs and synergies around land use and ecosystem services in scenarios that include and exclude climate change. Thus, GLOBIOM enables benchmarking of CSA's impacts against agriculture sector targets and the normative vision. See Appendix E for more details.

GLOBIOM has been used extensively to analyze the medium- and long-run effects of climate change (Leclère et al. 2014; Havlík 2015); deforestation (Schmitz et al. 2014); food security (Valin et al. 2014; Palazzo et al. 2017); and bio-fuel policies (Valin et al. 2013; Havlík et al. 2011; Mosnier et al. 2013; Frank et al. 2013) at the global and regional level. The model has also been used for several in-depth country case-studies, including deforestation assessments for the Congo Basin (Mosnier et al. 2014) and Brazil (Soterroni et al. 2018), and analysis of Russia and Ukraine's production potential (Deppermann et al. 2018).

The model computes the market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, contingent on resource, technological and policy constraints. Agriculture and forest productivity is based on input from two models: Environment Policy Integrated Climate (EPIC), Lund-Potsdam-Jena managed Land (LPJmL) and the Global Forest Model (G4M). GLOBIOM captures production systems and land use in the base year 2000, using historical data from the Spatial Production Allocation Model (SPAM; You and Wood 2006), which provides the physical area for 17 of the 18 crops included in GLOBIOM under four crop management systems: subsistence farming, low input rainfed, high input rainfed, and high input irrigated (Balkovič et al. 2013). Production is calibrated to match FAO's country-level statistics, and demand is modeled at the regional level using 30 economic regions which consist of single countries or bundles of countries based on food balance sheets developed by FAO (FAOSTAT 2017). GLOBIOM relies on a recursive dynamic approach combined with exogenous population and economic growth trends to create future projections for key indicators (See Table 2.6).

For this study GLOBIOM has been modified and updated with country-specific information to approximate Zambia's agriculture sector. This includes agricultural production statistics, land cover maps, and data on irrigation, costs, and livestock enabling the generation of a range of outcome indicators (see Table 2.6). GLOBIOM enables modelling of the impact of CSA practices on these indicators.

Exploratory scenarios were used to capture and model the high level of uncertainty arising from the development of outcome indicators. This framework is conducive to assessing uncertainties arising from climate change and the possible trajectories of socioeconomic drivers of agricultural growth. In Zambia, drivers of agricultural development include both local and global factors set out in

Table 2.6 GLOBIOM outcome indicators

Indicator	Definition
Crop production	Crop production is determined by the agricultural or forestry productivity of a specific area, which is in turn dependent on the crop suitability and management practices, market prices which reflect demand, and the conditions and cost associated with land conversion to agricultural purposes to expand production.
Crop yield	Using average crop yield provides an indication of the overall productivity of cropland and context for examining the potential impacts of CSA technologies.
Livestock production and heads of livestock	Livestock is modeled using a detailed representation of the global livestock sector in which distinctions are made among dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs (Havlík et al. 2014; Herrero et al. 2014). Livestock production activities are defined by production systems (Herrero et al. 2013): Ruminants, grass-based or mixed crop-livestock (arid, humid, and temperate/highlands), and other monogastrics, smallholders and industrial. For each species, production system, and region, a set of input-output parameters is calculated based on the approach set out in Herrero et al. (2013).
Cropland and land use change	Land use change is examined for irrigated and rainfed cropland, grassland, forest, and other natural lands to determine the extent to which productivity gains spare land for protection of terrestrial ecosystems and climate stabilization.
Calorie availability	Demand for crop products for food, livestock feed, bioenergy, and fiber is used as indicator for food security of a growing population. The analysis uses kilocalorie availability per capita per day to measure food security. It considers the total food products demanded by a region, and translates the quantity into calories.
Net Trade	Net agricultural trade (exports minus imports) is provided for a number of key agricultural commodities. The model assesses imports or exports as a share of domestic consumption, to assess relative dependence on trade partners.
AFOLU GHG emissions	GLOBIOM accounts for 10 sources of GHG emissions: nitrous oxide (N_2O) emissions created by fertilizer use; methane (CH_4) emissions from rice cultivation; CH_4 emissions from livestock; CH_4 and N_2O emissions from manure management; N_2O from manure applied on pasture; and above- and below-ground carbon dioxide (CO_2) emissions from biomass removal after converting forest and natural land to cropland. GLOBIOM cannot model below-ground carbon sequestration, which might occur with no tillage and agroforestry practices, or emissions from burning of biomass and savanna.

the shared socioeconomic pathways (SSPs) scenarios. SSPs capture a set of plausible potential future socio-economic developments in the absence of climate change and climate policies. For this analysis the projections of SSP2 "Middle of the Road" (Fricko et al. 2017) were adopted to represent a business-as-usual (BAU) scenario. Sensitivity analyses were conducted for SSP1 "Sustainability—taking the green road", and SSP3 "Regional rivalry—a rocky road". See Appendix E.1 for a description of all SSPs.

A combination of climate models is used to assess the impact of climate change by comparison with a BAU scenario. Five general circulation models (GCMs) and two crop models were used. The crop models EPIC and LPJmL provide the bandwidth of the yield shock caused by climate change in comparison to the absence of climate change. Yield simulations are performed for representative concentration pathway (RCP) 8.5, which shows the most extreme climate outcomes (Riahi et al. 2011) and a scenario variant with and without a carbon dioxide (CO_2) fertilization effect. See Appendix E.1 for details.

Section
3

State of CSA Adoption and Performance in Zambia

Section summary

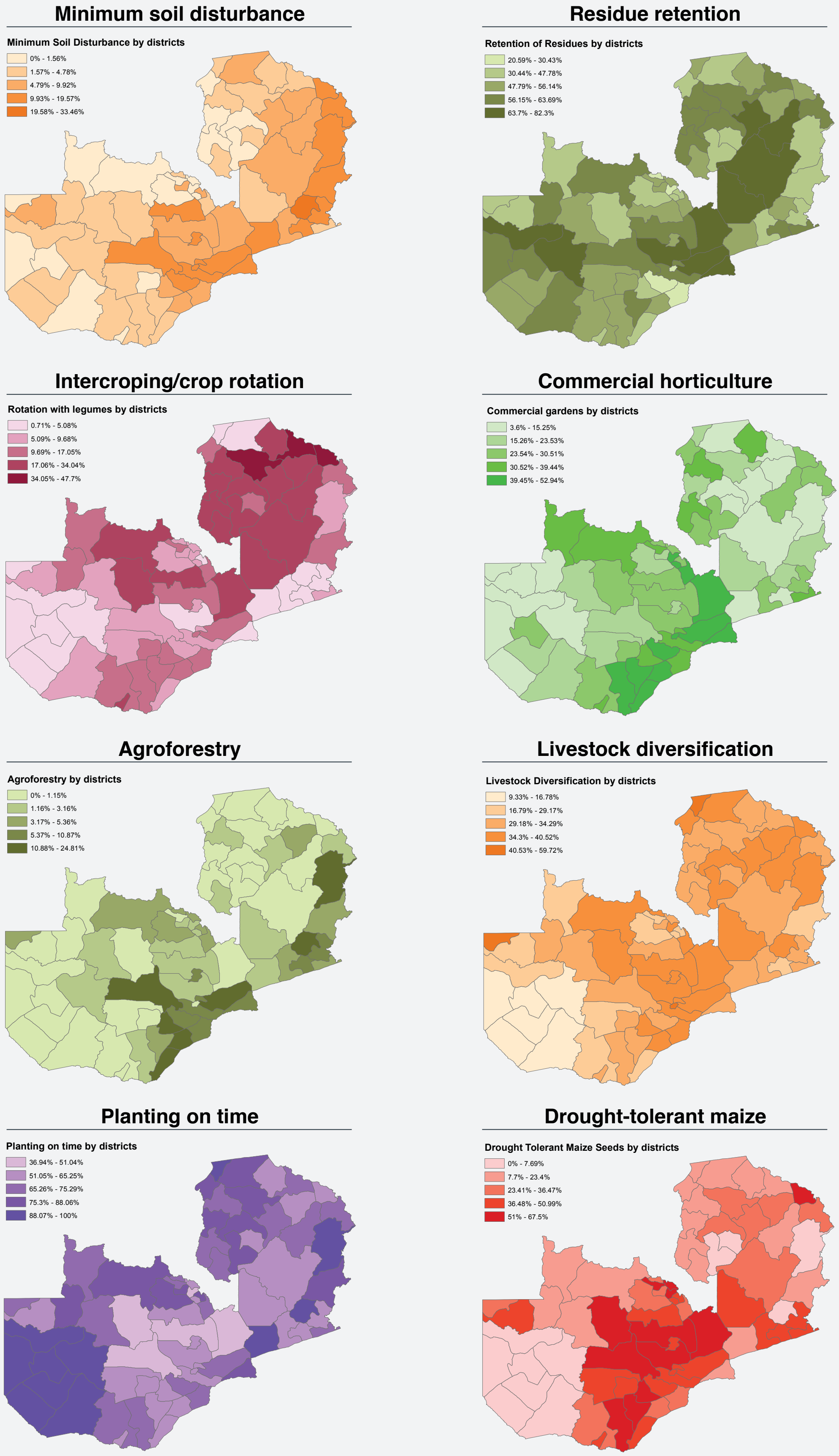
Several CSA practices have been piloted in Zambia. Figure 3.1 provides maps of CSA adoption, which ranges between 4 percent (agroforestry) and 60 percent (residue retention). Literature presented in this section shows that CSA has a high potential for increasing yields and income, under certain agroecological conditions and after several years (for example, agroforestry). Barriers to adoption are high and relate to labor costs (for instance, minimum soil disturbance) or the lack of production inputs (for example, mechanization and herbicides in minimum soil disturbance, saplings for agroforestry, seeds for drought-tolerant seeds, planting on time). Diversification towards livestock, legumes and horticulture are promising due to high domestic demand. Maize-centric distortionary policies, lack of rural market infrastructure, and outputs markets remain major constraints for smallholders.

3.1 Minimum Soil Disturbance

Minimum soil disturbance, mostly the use of planting basins or ripping, is practiced by 7.8 percent of smallholder farmers in Zambia. However, the cost and benefit track record is variable and context specific, which contribute to elevated risk and uncertainty for farmers (Pannell et al. 2014). Minimum soil disturbance is one of the pillars of conservation agriculture. Its goal is to avoid mechanical soil disturbance in agricultural activity. This is made possible by machinery that has been developed to allow sowing on plant residues, although it is necessary to select the type of machine best suited to the conditions of each farm.

In mechanized systems, minimum soil disturbance is associated with reduced production costs, mostly through savings in fuel and tractor use. However, weed management costs can be higher than for conventional practices (D'Emden et al. 2008; Erenstein et al. 2012). The possibility to utilize counter seasonal labor by preparing land in the dry season is another potential way to spread labor

Figure 3.1 Spatial distribution of adoption rates for eight CSA practices



Source: FAO, using RALS data

demand and lower costs. Labor demands associated with minimum soil disturbance may also vary with the duration of adoption. For example, the establishment of planting basins may require more labor hours relative to conventional practices, but once the basins are established, labor demand is less than for conventional practices (Haggblade and Tembo 2003). Weed management costs are typically higher when manual weeding is used in place of herbicides (Erenstein et al. 2012; Wall 2007; Giller et al. 2009). For many smallholder producers, herbicide use is not an option, due to lack of availability, resources, and knowledge. Field trial data from eastern and southern Africa shows a 50 percent reduction in labor demand for tillage with minimum soil disturbance, but a 30 percent increase in weeding demand.

In addition to the potential direct costs and benefits of minimum soil disturbance, indirect costs and benefits must also be considered. One such benefit, per Lal (2004), is that the use of minimum tillage reduces carbon emissions relative to conventional tillage from 35.3 kg carbon equivalents (CE)/ha to 7.9 kg CE/ha. A notable indirect cost of minimum soil disturbance is that using herbicides to achieve labor savings raises potential health and environmental costs. Moreover, the potential increased demand for manual weeding places a pronounced burden on women. Promotion strategies for minimum soil disturbance need to consider these indirect costs and identify strategies to mitigate them.

3.2 Residue Retention

Approximately 59 percent of smallholder households in Zambia leave their residues in the field, either as a form of mulch or for livestock grazing. The economic costs and benefits of residue retention, and barriers to adopting are highly context specific. Evidence from field trials and simulation models suggest considerable variability in yields (Baudron et al. 2012; Probert 2007). Residue retention has been found to support higher soil moisture levels in the following year, with beneficial effects on yields under dry conditions. However, yields have been found to decline following residue retention under high rainfall conditions (Rusinamhodzi et al. 2011). Residue retention is also found to reduce weed pressure under certain conditions, and thus can contribute to a reduction in weeding costs.

Yields tend to decline in the short term and increase in the long term. When residue retention is combined with minimum soil disturbance, yields typically decline relative to conventional practices and then begin to increase, typically exceeding conventional yields after a decade (Pannell et al. 2014; Fowler and Rockstrom 2001; Baudron et al. 2012). Given the high discount rates of smallholder farmers, delayed benefits are likely a major barrier to adoption.

Residue retention and management are also constrained by the common practice of communal grazing of crop stubble in many parts of Zambia, and the economic value of residues as animal feed. In areas with a high livestock density, it is unlikely that residues retained will be sufficient to meaningfully affect yields and yield stability (Mazvimavi and Twomlow 2009). High livestock density is more likely to be a challenge in AEZ I and AEZ IIa, where 7.3 percent of households have livestock (excluding poultry) in their farm system, as compared to about 2 percent of households in the other two AEZs. Burning residues is a common practice that provides a number of immediate benefits, including lowering weed pressure, facilitating the hunting of mice, and providing some soil nutrients; burning residues also contributes significantly to Zambia's carbon footprint.

3.3 Legume Rotation and Intercropping

49. In Zambia, 8.5 percent of smallholder farmers practice legume rotations and 13 percent practice legume intercropping. Growing legumes in rotation or as an intercrop can provide several benefits,

such as increased crop yields and a reduction in input costs due to nitrogen fixation, a reduction in crop disease, and other potential advantages (Pannell et al. 2014; Pannell 1995). While legume rotations generally confer yield benefits on cereal crops, the overall benefits to a farm household of incorporating legumes depend on the price and/or yields generated by legumes. Identification of grain legume species with reasonable levels of market development is therefore essential for the overall economic attractiveness of legume rotations and intercroppings. For example, Rao and Mathuva (2000) found that annual grain legume-based cropping systems (based on cowpea and pigeon pea) were 32–49 percent more profitable than growing maize continuously, while rotation with gliricidia was less profitable than continuous maize.

In terms of the legume market in Zambia, groundnuts have significant domestic demand due to their importance in the Zambian diet. While there are export and value-addition (peanut butter) opportunities for groundnuts, these are not widely exploited in Zambia. Soybeans are important for the animal-feed and oil industries. The soybean market is growing rapidly, but prices are also falling. Cowpeas are not widely consumed, but pigeon peas are an emerging crop in Zambia but depend on the Indian market. Finally, common beans are widely consumed in Zambia, with production concentrated in the north of the country. The choice of rotation versus intercropping is also important as it entails trade-offs in terms of land allocation and yields at the farm level. For example, legume rotations in the Eastern Province generate higher average maize yields than intercrops for most legume species, but intercrops are preferred by the majority of farmers due to land constraints (Thierfelder et al. 2017).

3.4 Commercial Horticulture

In Zambia, approximately 23 percent of smallholders, or 370,000 households, produce fruits and vegetables for sale. Analyses of the smallholder horticulture sector in Zambia suggest considerable opportunities to link smallholder producers to the country's urban sector, in ways that can produce beneficial opportunities for poverty reduction and economic growth (Tschirley et al. 2014; Hichaambwa et al. 2009). Based on urban consumption data, the average household in Lusaka spends roughly 21 percent of its food budget on horticulture products, second only to its expenditure on cereals (24 percent) (Hichaambwa et al. 2009; Chisanga and Zulu-Mbata 2018). In 2012, the total value of fruits and vegetables sold by smallholders in Zambia was approximately US$250 million and the prospects for continued demand growth for horticulture products remain high. Commercial horticulture can increase incomes for land-constrained farmers, many of which are women and produce gross margins 138–219 percent higher and returns that are 141–263 percent higher than for maize (Hichaambwa et al. 2015).

As a result of rapid growth of supermarket outlets, there is a concern that smallholder producers will be excluded from emerging market opportunities for horticulture products in urban Zambia. There is substantial evidence that smallholders often struggle to meet the supply quantity, quality, and consistency requirements of export markets (Dolan and Humphrey 2000). While these concerns are valid, there is evidence that domestic horticulture markets in Africa and Asia, unlike those for meat and dairy, are often resistant to retail consolidation (Tschirley et al. 2014; Weatherspoon and Reardon 2003). Indeed, Tschirley and Hichaambwa (2010) estimate that over 90 percent of horticulture products consumed by urban Zambians are purchased through traditional market retailers.

Despite growth opportunities, major constraints exist within the horticulture sector. First, smallholder markets are quite concentrated, with the top 20 percent of sellers accounting for over 80 percent of sales. Moreover, a minority of horticultural producers in Zambia are sellers; the likelihood of selling rises steadily with landholding size (Chapoto et al. 2012). Second, remoteness is a major factor in determining market participation. Due to perishability and susceptibility to damage, farmers that are far from urban markets are unlikely to sell horticulture products. Third, barriers to entry include the comparatively high financial and human capital investment, and the need to understand supply chains. Small-scale irrigation is needed year-round to produce crops throughout the year. Finally, high levels of price uncertainty and generally chaotic conditions within urban wholesale markets place significant risks on farmers and limit market participation (Hichaambwa et al. 2015).

3.5 Agroforestry

In Zambia, four percent of smallholders practice agroforestry. As compared with conventional maize cultivation, agroforestry in Zambia entails higher labor costs during the first and third years. Most frequently planted Agroforestry species include *Faidherbia albida*, Musekes (*Piliostigma thonningii*), Mpundu as well as *Gliricdia sepium*, *Sesbania sesban*, *Tephrosia vogelii*, Nyamundalo, Acacia. The literature on agroforestry in Zambia suggests the potential for financial gains from adoption, but raises concerns about discount rates, up-front labor costs, sapling availability, lack of skills to develop a nursery, the need to leave plots fallow until the third year, lack of long-term tenure security under customary land tenure systems, and livestock grazing on customary land. Higher costs in the first and third year are due to the need to establish and cut the trees and incorporate them into the soil. During the other years, labor costs relative to conventional agricultural production are lower, and agroforestry requires less labor overall over a five-year period than maize production systems (Ajayi et al. 2010).

In terms of financial profitability, agroforestry is found to produce a discounted NPV of between US$233 and US$309/ha over a five-year period, depending on the species, through positive impacts on crop yields and income generated from agroforestry by-products such as firewood. This compares favorably with an NPV of US$130/ ha for unfertilized continuous maize production. However, continuous maize cultivation without fertilizer subsidies is found to be 13 percent more profitable than agroforestry; maize cultivation with subsidies for fertilizer is 61 percent more profitable (Ajayi et al. 2010). Access to subsidized fertilizer decreases the economic rationale to adopt agroforestry. Targeting the promotion of agroforestry to households that have limited access to fertilizer may offer the best opportunity to promote adoption (Place et al. 2003). Also, strategies to shorten the initial fallow period from two years to one may help improve agroforestry's financial attractiveness to smallholders (Ajayi et al. 2010).

3.6 Livestock Diversification

Zambia's livestock sector contributes an estimated 42 percent of the total value of national agricultural output. As of 2015, 64 percent of smallholder farmers (primarily in the Southern, East and Central Provinces) raised "village chickens," 24 percent owned cattle, and 27 percent owned goats. (Bwalya and Kalinda 2014). Given rapid income growth in urban Zambia, demand for livestock products has grown remarkably over the last decade, creating new market opportunities for smallholder producers. Lubungu et al. (2015) estimate that smallholder cattle and goat populations in Zambia doubled to 2.8 million and 2.4 million animals, respectively between 2008 and 2012. Poultry production has increased even more rapidly, with broiler chicken populations increasing threefold to reach 36 million birds between 2001 and 2011 (Bwalya and Kalinda 2014). Livestock ownership confers a range of economic and social advantages in Zambia, from sale income and household consumption to more indirect benefits including as a source of livelihood insurance, animal traction, and manure production (Moll 2005).

Livestock is negatively affected by climate change. Investing into certain species has the potential to serve as an important tool for livelihood resilience in the context of climate change. Livestock diversification can increase tolerance to drought and heat waves and is effective against climate change-related outbreaks of diseases and pests (Rojas-Downing et al. 2017). High temperatures can affect growth, reproduction performance, production, and animal health and welfare (Arslan et al. 2018). Climate change has already increased the number of recorded animal disease outbreaks in Zambia. For example, six weeks of drought in January 2018 coupled with subsequent irregular, often heavy, precipitation caused the death of many cattle. As temperatures rise, investing in livestock such as donkeys, pigs, rabbits, poultry or sheep and goats rather than ruminants may not only increase resilience but also enable continuous meat and milk production (Arslan et al. 2018).

Increasing livestock ownership and realizing the potential associated benefits for households through commercialization presents several challenges. First, animal husbandry capacity is low. Smallholders rarely utilize livestock vaccines or veterinary treatments, instead relying on traditional treatments. The use of supplemental feeding is low in Zambia, which leads to significant seasonal variations in weight and reproductive performance. Second, government support for the livestock sector, for instance in the form of dip tanks, veterinary services, and oversight of processing facilities remains low. Third, sociocultural norms related to livestock ownership, particularly cattle, may limit the potential for commercialization. Cattle are often acquired as part of marriage dowries and are thus the property of extended families and not of individuals, which complicates marketing decision-making. Finally, disease outbreak and a lack of market segmentation for improved meat quality limits investments in formal livestock market development and adoption of improved management practices (Lubungu et al. 2015).

3.7 Timing of Planting

In rainfed production systems, the timing of planting is an important determinant of crop yields. In Kenya, Tittonell et al. (2008) find that early planted maize crops achieved yields of 2.1 MT/ha, nearly double the 1.2 MT/ha yield of late planted crops. Further, each day the planting date of seed cotton was delayed or the length of the rainy season was reduced, was associated with an average reduction of 16 kg/ha in attainable yields (Tittonell and Giller 2013). The timing of planting is a function of the length of the rainy season and temporal distribution of rainfall as well as of crop and seed variety choice. In Zambia, maize planted after December 15 is typically considered delayed. This date serves as a rule of thumb; appropriate planting dates vary between regions and the maturation length of the seed used.

Delayed planting in smallholder systems is caused by a range of factors. For asset-poor households, availability of labor and/or animal traction is an important contributing factor to delays in planting. In many cases, poor households perform day labor, or *ganyu* as it is called in Zambia, during the planting season in order to meet household food security needs. This diverts scarce labor away from production on households' own fields, and can contribute to a vicious cycle of piecework, food insecurity, and low productivity. Traditional seed varieties, which are commonly adopted by resource-poor households, typically have longer maturation lengths than those hybrid varieties. In areas where growing seasons are short, there is limited window for timely planting of these varieties. Market isolation may also be an important driver for delayed planting, as it limits the availability of improved seed varieties. Finally, under Zambia's input subsidy program FISP, the delivery of inputs to farmers is often late. Namonje et al. (2015) estimate that in 2012, 21.5 percent of subsidy recipients received inputs late. Late delivery of inputs contributed to a 4.2 percent reduction in maize yields, or roughly 84,000 MT at a national level.

3.8 Drought-Tolerant Maize

Drought stress is a common challenge in Sub-Saharan Africa. It is estimated that roughly 40 percent of Africa's maize-growing area experiences occasional drought stress, with yield losses of 10–25 percent. An additional 25 percent of the maize crop in Africa suffers frequent drought, with losses of as much as half the harvest (Cairns et al. 2013). Investment in the development and promotion of drought-tolerant seed varieties that are bred to sustain yields under dry conditions can contribute to significant benefits for producers and consumers in the region.

Breeding of drought-tolerant maize varieties began in earnest in Zambia in 2007 as a result of the Drought Tolerant Maize for Africa project, led by CIMMYT and conducted in collaboration with Zambia Agricultural Research Institute (ZARI). Through this project, 160 varieties of drought-tolerant maize have been released in 13 countries. In Zambia, an estimated 23 percent of farmers utilize drought-tolerant maize varieties (Fisher et al. 2015). La Rovere et al. (2010) estimate that adoption of drought-tolerant seed varieties can improve average maize yields in Zambia by 17.3 percent and reduce the variance in yields associated with dry conditions by 10–15 percent. A full replacement of improved maize seeds with drought-tolerant maize seeds in Zambia would lead to total economic benefits of US$115 million, of which US$74 million come from yield growth and US$41 million from reduced yield variance. This would pull an estimated 360,000 Zambian households out of poverty.

Key barriers to adoption of drought-tolerant maize varieties include: low availability of improved seed, inadequate information, lack of financial resources, high seed cost, and negative perception about the taste and storability of different varieties (Fisher et al. 2015). Stimulating greater private investment in the multiplication and delivery of drought-tolerant seed, as well as developing marketing arrangements to reach poor segments of the rural population, such as selling 1–2 kg micro packets of drought-tolerant seeds, are critical for addressing adoption barriers.

3.9 Crop Diversification

Zambia exhibits one of the lowest levels of crop diversification in Africa as measured by the Simpson's Diversity Index. About 48 percent of smallholder farmers cultivate three or more crops while 14 percent grow maize in monocrop (Maggio et al. 2018). As shown in Figure 3.1, provinces in the north and northeast have the highest crop diversification while south and central regions of Zambia are the least diversified. Livestock diversification is higher in provinces in the east and south of the country than other areas (Arslan et al. 2015). A descriptive analysis of the RALS 2012 and 2015 shows that 15–41 percent of households have low levels of livelihood and agricultural diversification, respectively.

The impact of crop diversification on household welfare in Zambia is highest for low income households and lowest for wealthy households. However, wealthier households are the most likely to adopt more diverse crop production systems. The rural poor face significant adoption barriers to diversification (Ignaciuk et al. 2018). Given land constraints, households often prioritize the production of staple foods on their available land. The rural poor often face greater constraints in access to input and output markets, agricultural credit, and extension services, which limit their capacity to diversify. Crop diversification in Zambia is associated with a reduction in crop income volatility and, in many cases, with increased maize productivity (Maggio et al. 2018). The key drivers of crop diversification include access to more competitive private output markets, increasing land size, and exposure to adverse weather conditions. Proximity to the FRA, significantly reduces the probability of crop diversification (Ignaciuk et al. 2018; World Bank 2018d).

3.10 Agricultural Liming

Zambian soils show high levels of acidity, which can be addressed by agricultural liming. Burke et al. (2017) estimate that a soil pH of 5.4 marks a threshold below which yield responses to basal fertilizer drop off substantially. For Zambian soils an average level of acidity of soil pH 5.38 is assessed, which hinder the retention of potassium, calcium and magnesium, and other essential elements and limit the availability of phosphorous derived from both the soil and fertilizers. Soil microbial activities and root growth are negatively influenced, and crop yield is decreased. The authors estimate that 25–45 percent of basal fertilizer users in Zambia operate at a fiscal loss. Put differently, Kelly (2005) suggests that smallholder farmers, who plan to adopt a new technology but are risk averse, need an average value-cost ratio of 2 to adopt a new technology. At this threshold, virtually no farmer in Zambia breaks even using basal fertilizer. Raising soil pH with agricultural lime in Zambia yields potentially great economic benefit. However, the quantities required to have a meaningful effect on pH levels are substantial. To move soil from a pH of 5, which marks the 25th percentile of smallholder soils in Zambia, to a pH of 5.2 (marginally below the yield response threshold estimated by Burke et al. (2017)) would require 2–3 MT/ha of lime, and approximately 4 MT/ha to reach a pH of 6 (Sims 1996).

Table 3.1 Comparative descriptive statistics on lime adopters and non-adopters

	Non-adopters	Adopters		
	Mean	Mean	Difference	T-Test
% of households that are female headed	0.258	0.206	0.053	
Avg. years of education completed by the head of household	5.704	7.103	-1.399	**
Number of household members in adult equivalent	5.141	5.798	-0.656	
Avg. agricultural wealth index (0 to 1)	0.078	0.173	-0.095	***
% of households with less than 5 hectares cultivated	0.783	0.655	0.128	
% of households applying inorganic fertilizers	0.615	1.000	-0.385	***
% of households participating in Zambian FISP	0.371	0.423	-0.052	
% of households that are members of a coop, farmer/women/ savings-loan group	0.507	0.577	-0.071	
% of households that received information on conservation agriculture	0.378	0.497	-0.119	**
Commercialization index (0 to 1)	0.302	0.431	-0.129	**
% residing in AEZ I	0.085	0.081	0.005	
% residing in AEZ IIa	0.367	0.448	-0.081	
% residing in AEZ IIb	0.072	0.000	0.072	***
% residing in AEZ III	0.476	0.471	0.004	

Source: RALS 2015.
Note: Significant levels of T-test are * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Unfortunately, adoption rates for agriculture lime among Zambian smallholders is too low to conduct a meaningful econometric analysis of its impacts. The descriptive details on lime adopters relative to non-adopters are therefore presented here in, with T-tests to assess the statistical significance of the differences between adopters and non-adopters. In 2014-2015 only 53 of the roughly 6,000 households in the RALS used lime on their fields. As shown in Table 3.1, there are a number of significant differences between lime users and non-lime users in Zambia's smallholder sector. The heads of households that use lime have on average 1.4 more years of education. These households own significantly more agricultural assets, as measured through an agricultural asset index. They are also significantly more likely to use inorganic fertilizer and to receive information on conservation agriculture. Indeed, 100% of lime users also use inorganic fertilizer. On average lime users commercialize a greater share of their agricultural output than non-users. As shown by the commercialization index, the average lime user sells 43% of the value of all agricultural products they produce, compared to 30% among non-users. Finally, there are no lime users included in the survey that reside in the semi-arid AEZ IIb. This is unsurprising, given the relative market isolation in that region and the region's low potential for rain-fed crop production.

3.11 Post-Harvest Loss

Following the food price crisis in 2007/2008, there is a renewed interest in reducing post-harvest losses. The World Bank (2011a), estimated that around US$4 billion annually can be saved in Sub-Saharan Africa by reducing the post-harvest loss in grains (mainly cereals and legumes). This is more than the value of total food aid received in the region over the last decade. There are four major reasons to address post-harvest loss (Sheahan and Barrett 2017): (1) improve food security; (2) improve food safety; (3) reduce unnecessary input use and (4) increase profits for food value actors. Food loss and waste can take place at all stages of the value chain between the farmers' field and the consumers' fork, which can be divided into five stages (FAO 2011): (1) harvesting due to mechanical damage and/or spillage, (2) post-harvest loss, which includes drying, winnowing, and storage (insect pests, rodents, rotting), (3) processing, (4) distribution and marketing, and (5) consumption.

Most data on post-harvest loss is spotty and often of poor quality. None of the available sources provide data for Zambia. FAO (2011) estimated that total post-harvest loss in Sub-Saharan Africa amounts to one third of total food produced (in volume). A more comprehensive analysis is presented by Affognon et al. (2015), who conducted a literature survey of post-harvest loss in six African countries (but not including Zambia) and seven commodity categories. On average, post-harvest loss for groundnuts ranges up to 35 percent, for maize 25 percent and for mango even up to 55 percent. Kaminski and Christiaensen (2014) use nationally representative household surveys for Uganda, Tanzania and Malawi and show that on-farm post-harvest loss for maize is in the range of 1.4–5.9 percent. There is a consensus that most grains and cereals are lost during post-harvest handling and storage on-farm, while loss of fresh produce, meat, and seafood is concentrated in processing, packaging, and distribution (Sheahan and Barrett, 2017). In Sub-Saharan Africa, most post-harvest loss happens at the farm level (FAO 2011; Affognon et al. 2015).

Section

4

Analysis Results: Observed Impacts of CSA on Household Welfare

Section summary

The household level econometric and financial assessments of the impacts of CSA adoption corroborate findings from the literature (see Section 3), as follows:

- The **long-term, positive welfare effects**, such as increased gross income and income from crops, increased food availability, and reduced levels of poverty can be confirmed for most CSA practices.
- In the **short term, high production and labor costs** hamper the adoption of CSA practices, specifically minimum soil disturbance, residue retention, and agroforestry. These practices, as well as crop rotation, sequester high levels of carbon in the soil and thus offer significant climate mitigation potential (Section 5.7).
- The **performance of CSA practices varies across agroecological zones** and shows varying degrees of climate sensitivity, as measured by rainfall variability. Minimum soil disturbance, residue retention, and small-scale horticulture are not well suited to very wet conditions due to waterlogging and weed pressure, or because lack of drainage. Drought- and heat-tolerant seeds, agroforestry, and crop diversification show good results under both extreme dry and wet conditions, and seem particularly suited to climate adaptation and resilience building practices.
- At the household level, adoption of CSA practices can exert a **positive impact on rural development** in the form of market and job creation. The need for adequate mechanization or timely delivery of inputs creates opportunities for developing markets; also legumes, livestock, and horticulture have high value addition potential. All CSA practices—particularly those with varying climate sensitivity—benefit from targeted agricultural advisory services that can mitigate the risks of adoption.

This leads to three recommendations to support CSA adoption:

1. Provide access to finance and/or subsidize farmers for high upfront cost.
2. Support development and promotion of practices customized to agroecological conditions.
3. Support market development for tools and services such as inputs (for example, seeds) and advisory services (for instance, customized, ICT-based agronomic advice to enhance timing of planting) that support CSA adoption.

This section is organized according to CSA technologies and shares findings from two different analytical approaches (both econometric and cost-benefit analyses). Owing to data constraints, CSA practices are analyzed discretely—although some farmers adopt practices in combination. Detailed results are presented in Appendix C.3.

4.1 Findings: Analysis of Minimum Soil Disturbance

The primary adoption barriers that farmers face with minimum soil disturbance (MSD) is an increase in direct costs, particularly labor (see Table 4.1). Addressing direct costs is essential for achieving widespread adoption of minimum soil disturbance. Given the food security and income risks for households associated with changes in farm practice, low income may discourage autonomous adoption and retention of CSA practices over time.

Table 4.1 Main findings of the econometric analysis: Minimum soil disturbance

Analysis	Main findings	Interpretation
DiD analysis	• Adoption increases the probability of household poverty	• Poverty effect stems from short-term perspective of the DiD approach. Thereby, high upfront cost play a large role
OLS model	• Correlated positively with crop income and gross household income; there is a negative relationship with income variability and poverty	• This cannot be interpreted as causality but as long-run positive correlation, suggesting that adopting MSD for several years is correlated with a reduction in income variability and poverty.
Climate sensitivity	• Increases gross-income variability • In areas of heavy rainfall MSD adopters experience 23% reduction in crop income relative to conventional tillage farmers	• Coefficients are too low to allow a meaningful interpretation • Trend likely due to high weed pressure and/or water logging of planting basins under MSD
Crop yields and production cost	• Crop yields under MSD are higher than under conventional practices in areas with low or medium rainfall (AEZ I, IIa, and IIb). Maize yields under conventional practices in AEZ III are much higher than under MSD • Disparity in crop yields by MSD-combination: With legume rotation, yield is 2.8 MT/ha for maize in AEZII; planting basins achieves yield of 2.1 MT/ha. • MSD requires more labor than conventional tillage due to land clearing and planting basins	• Crop yields under MSD tend to be higher on average than conventional practices in dry areas • These findings appear to be mostly due to increased labor costs and the upfront costs of adoption, which combined with the high discount rates and risk aversion of most poor smallholder households, limits adoption among this socioeconomic segment
Financial viability for households: Net incremental benefits per hectare	• Financial returns per hectare of MSD are mostly positive but small • Highest net incremental benefits across AEZs are evident for rice (US$163/ha), followed by soybeans, groundnuts and cowpeas (US$97/ha, US$79/ha, US$65/ha); lowest for beans (US$ -3.2/ha). • In contrast with drier AEZs, net incremental benefits in AEZ III are negative for maize and beans (US$ -79/ha and US$ -24/ha) but highest for cassava (US$74/ha). • For maize, highest benefits are found in AEZs I, IIa and II, where average incremental benefits are US$30/ha.	• Low returns deter autonomous adoption of CSA practices • MSD is best suited to rather dry AEZs (I, IIa, IIb) and may produce low or negative results in AEZ III. Cassava, an exception, shows highest results in AEZ III • However, while net incremental benefits are higher for some other crops, benefits associated with maize production will likely drive decisions at the household level

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses and financial analyses; see Appendix C.3 and D.3 for detailed results.

Household level cost-benefit ratios vary significantly across agroecological zones (AEZs) and crops. In high rainfall regions of Zambia, such as AEZ III, minimum soil disturbance should be adopted cautiously as net benefits are small or even negative. For instance, results for maize are mixed: in AEZ II minimum soil disturbance yields positive but relatively low incremental net benefits but could cause financial losses in AEZ III. Given the uncertainty of results, poor households may find it difficult to sustain adoption of MSD and will need significant support to cover upfront cost. Adjusting practices to varied biophysical conditions would be crucial (see Appendix D for detailed results of the financial analysis).

Widespread adoption of MSD would likely support the creation of new markets for implements and inputs, including direct seeders, chisels and/or rippers, *chaka* hoes, and herbicides, and would bolster rural development. The need for advisory services would probably create new jobs as well.

4.2 Findings: Analysis of Residue Retention

Residue retention reduces income variability and household food insecurity in the long term, particularly in dry regions. In the short term, retaining crop residues does not have a significant effect on most welfare indicators relative to conventional practices, with the exception of income variability, which it seems to reduce. In the long term, residue retention can be expected to increase income, particularly in dry regions. While input costs can be reduced, higher labor costs present an issue. Residue retention offers higher food security benefits in dry regions such as AEZ I; in wetter areas, the practice had a negative impact on yields and incomes, which suggests that appropriate residue retention strategies should be identified before promoting the practice in wetter areas such as AEZ III (see Table 4.2).

Table 4.2 Main findings of econometric analyses: Residue retention

Analysis	Main findings	Interpretation
DiD analysis	• Reduction of 17.4% in income variability	• Residue retention has the potential to enhance resilience by decreasing variability and potential losses
OLS model	• In the long term, residue retention is correlated with an increase in crop income, but no other welfare indicators	• Lack of impact on other welfare factors might be due to low production and livestock pressure
Climate sensitivity	• Household food insecurity reduced by 23.6% under low rainfall scenario • In high rainfall areas, residue retention is associated with a 17.4% reduction in average income and an increase the probability of poverty	• Food security benefits are positive in dry, but negative in wet areas • In dry areas, residue retention can be expected to have a positive impact on soil moisture, likely linked to improved water retention capacity and reduced crop losses.
Net incremental benefits	• For maize systems in AEZ IIa residue retention combined with MSD led to a 30% and 11% increase in yield, and 182% and 16% increases in net margin per ha, compared with conventional and MSD-only systems • Compared to MSD-only, fertilizer costs can be expected to decline, and labor costs to increase by 7% and 33%, respectively	• Residue retention works well in combination with MSD and has a positive effect on crop yields • While net margins are expected to increase, this may be dampened by a simultaneous increase in labor costs

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses and financial analyses; detailed results are in Appendix C.3 and D.

Adoption of a well-managed residue management system may be constrained by two factors: the high costs associated with fencing fields in the dry season, as well as insecure land tenure. Grazing access on customary land may be a limiting factor for smallholder farmers. Where open grazing is the norm, the ability to fence fields is essential for managing residues. This entail high costs and requires more secure land tenure. In addition, residue retention offers negligible potential for job creation and value-chain development and thus is not an effective agent for broad-based rural development.

4.3 Findings: Analysis of Legume Rotation and Intercropping

Legume rotation and/or intercropping does not show a significant short term effect, but a positive correlation with crop income in the long term. Low crop yields are a concern. Adoption of drought-tolerant legumes seems to reduce food insecurity under dry conditions and enable higher crop productivity and two production cycles in wetter regions (see Table 4.3). Average legume yields are 40 percent lower in Zambia, compared to countries in the region. Addressing low yields in Zambia is likely a key priority for enhancing adoption of legumes in smallholder systems and improving the welfare impact. This may require a combination of investments in improved seed varieties, particularly promiscuous varieties, management practices for key legume varieties and/or support for legume market development.

Growth in the legume sector holds significant potential in terms of job creation and value chain development, including: investment opportunities in legume processing and export; and job opportunities in legume seed multiplication, input supply, and off-taking. This could contribute to a reduction of protein deficiency in the Zambian diet and to improved nutrition outcomes in the country.

Table 4.3 Main findings of econometric analyses: Legume rotation and/or intercropping

Analysis	Main findings	Interpretation
DiD analysis	• No significant short-term impacts on welfare indicators	• One explanation might be low yields and low farm gate prices • Average yields of groundnuts, beans and cowpeas were 41% higher in other African countries than in Zambia.[a] This points towards the need to invest in improved varieties.
OLS model	• Significant long-term correlation between adoption and crop income • Limited correlation with other household welfare indicators	
Climate sensitivity	• Household food insecurity reduced by 10.4% in low rainfall scenario • Crop income variability reduced by 15% in high rainfall scenario	• Potential to reduce food insecurity may be due to adoption of drought-tolerant legumes • Reductions in income variability potentially due to higher productivity levels of legumes under wet conditions
Impact on alternative development indicators	• Significant potential for growth in the overall legume sector • Widespread protein deficiency in the Zambian diet could be addressed through increased legume production	• Investments in legume processing, exports, and legume seed multiplications should be explored

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses; see Appendix C.3 for detailed results.
(a) Comparing RALS 2015 and FAOSTAT 2018 data.

4.4 Findings: Analysis of Small-scale Commercial Horticulture

Adoption of small-scale horticulture provides a significant short- and long-term boost to gross income, and reduces gross income variability and poverty. The benefits, by comparison with non-adoption, are especially pronounced in dry climates. Small-scale horticulture also promises potential job creation and value chain benefits, although these are difficult to quantify. In addition, enhanced horticulture market participation in Zambia is likely to have a beneficial nutritive effect through direct consumption on-farm or by making horticulture products more widely available and affordable in local markets for urban and rural consumers (see Table 4.4).

Table 4.4 Main findings of econometric analyses: Small-scale commercial horticulture

Analysis	Main findings	Interpretation
DiD analysis	• Adopters saw crop income and gross income increase by 9.7% and 6.7% • 4.8% reduction in gross income variability and 1.7% decreased likelihood to fall below poverty line	• Despite high levels of market-price variability, horticulture products are typically short-duration crops that can be produced throughout the year with small-scale irrigation • This allows households to smoothen their income.
OLS model	• Results aligned with those from DiD model	
Climate sensitivity	• Adoption is highly beneficial in a low rainfall scenario, with households experiencing: 21% increase in crop income; 25% increase in gross income; 19.1% reduction in the probability to be poor; 16% reduction in the probability of food insecurity under dry conditions	• A short production duration enables producers to better match production cycles with rainfall cycles • Feasible placement of horticulture fields near perennial water sources
Impact on alternative development indicators	• Broadly positive, especially in combination with investments in value-adding process such as canning and juicing	• High income increases, especially for small farmers, if barriers to entry can be overcome

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses; see Appendix C.3 for detailed results.

4.5 Findings: Analysis of Agroforestry

In the longer term, adoption of agroforestry is correlated with beneficial impacts on resilience and risk. Agroforestry reduces by 25 percent the probability of food insecurity in both lower and higher rainfall conditions, making it a suitable CSA technology for scenarios in which climate change is significant. Upfront investment, forgone revenue, and delayed returns make agroforestry not well suited to adoption by smallholders, particularly at high cost of capital (discount rates), unless smallholders are directly and financially compensated, for example, via conditional cash transfers. With respect to rural development indicators, there is only small potential for job creation because agroforestry relies primarily on household labor; however, there is potential also for development of privately-owned nurseries (see Table 4.5).

Table 4.5 Main findings of econometric analyses: Agroforestry

Analysis	Main findings	Interpretation
DiD analysis	• No short-term causal effect	• Multiple years are required to establish beneficial agroforestry systems
OLS model	• Correlates closely with reductions in crop- and gross-income variability	• Findings are not causal, but do suggest a positive association
Climate sensitivity	• Adoption reduces food insecurity in both low and high rainfall scenarios by as much as 25%	• One explanation is that agroforestry leads to improved water retention and water infiltration
Impact on rural development indicators	• Neutral to modestly positive results in term of key development indicators	• High income increases, especially for small farmers, if barriers to entry can be overcome

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses; see Appendix C.3 for detailed results.

4.6 Findings: Analysis of Livestock Diversification

At the household level, livestock diversification contributes to lower levels of poverty and higher levels of food security and resilience, and these impacts may be even pronounced under climate change (see Table 4.6). Livestock ensure greater resilience in droughts and provide financial compensation for crop income lost to heavy rainfall. Diversification typically occurs in one of two ways. Households integrate livestock into their crop systems to diversify their agriculture production systems; alternatively, livestock owners diversify their livestock base to spread their production risk or exploit different market opportunities.

Livestock boosts rural development by providing opportunities for job creation, including veterinary services, trading, livestock processing and cross-border trade. Livestock products are also amenable to a wide range of processing- and marketing-related value addition options. Improved access to livestock proteins would broadly benefit nutritional outcomes in Zambia. The high ownership and management costs associated with rearing livestock present an obstacle to adoption by the very poor.

Table 4.6 Main findings of econometric analyses: Livestock diversification

Analysis	Main findings	Interpretation
DiD analysis	• Integration of livestock into crop systems reduces the probability of poverty incidence but exerts no impact on gross income • No significant impact on agricultural income, household income, and income variability	• Poverty reduction is likely achieved through a reduction in costs, including for land preparation, and the use of animal manure in place of fertilizers • Lack of commercialization in the sector limits the capacity of smallholders to turn livestock assets into cash
OLS model	• In the short and long term, diversification into new livestock species has very small, positive impacts on income variability and food insecurity	• Diversification into new species may delay positive impacts on welfare indicators due to the lack of or more volatile markets, or higher disease pressure.
Climate sensitivity	• In dry conditions, the integration of livestock into crop systems, shows a small positive effect on agricultural incomes and the probability of poverty • Under high rainfall conditions, livestock ownership is associated with a reduction in both agricultural and gross household income variability • The diversification into new livestock species under low rainfall conditions is associated with a reduction in food insecurity, but also an increase in gross income variability	• In the dry season, livestock owners benefit from the relative drought resilience of livestock • Livestock ownership smoothens the adverse effect of heavy rainfall on crop income • During drought, livestock may provide additional or alternative food sources, but liquidation of livestock holdings may result also in greater income variability
Impact on rural development indicators	• Multiple positive effects including income stability, increased household income, job creation, and value chain development opportunities	• Job opportunities include veterinary services, trading, livestock processing, and cross-border trade

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses; see Appendix C.3 for detailed results.

4.7 Findings: Analysis of Timing of Planting

Accurate timing of planting is especially important in dry conditions, such as those of Zambia's AEZs I and IIb, where growing seasons are particularly short (see Table 4.7). Enabling farmers to plant in a timely manner, either by supporting access to seeds of a duration appropriate to specific agroecological circumstances or by addressing labor and/or mechanization constraints that delay planting, would have significant positive effects, particularly on crop and household income and income variability. Poorer households face the greatest challenge to access the seeds, labor, and equipment needed to plant in a timely fashion. Developing strategies to improve the timing of planting will likely produce moderate positive benefits to the poor.

Table 4.7 Main findings of econometric analyses: Timing of planting

Analysis	Main findings	Interpretation
DiD analysis	• No significant short-term effects on welfare indicators	• Delayed planting did not happen in first wave of the survey
OLS model	• In the long term, households that plant late have on average 8.7% lower crop incomes, 46.3% greater crop income variability, and 8.6% lower gross household incomes than households that plant in a timely manner	• Delayed planting, which can occur in response to weather conditions, can hurt households' welfare. Supporting farmers to be more timely in planting can have important beneficial effects
Climate sensitivity	• Negative effects of delayed planting are exacerbated under adverse weather conditions, especially dry conditions	• Proper timing for planting is especially important in climate extremes, which points toward the need to support farmers with information on planting times and timely access to inputs
Impact on rural development indicators	• The value-chain and job-creation impacts of this strategy are modest	• Positive outcomes are mainly achieved through increase in production

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of results of statistically significant econometric analyses; see Appendix C.3 for detailed results

4.8 Findings: Analysis of Adoption of Drought- and Heat-tolerant Seeds

Despite evidence that improved seeds offer robust and consistent benefits across welfare indicators, fewer than half of all seeds used in Zambia qualify as drought- or heat-tolerant (see Table 4.8). Since poor households typically face the greatest hurdles in accessing improved seeds, targeted interventions are needed.

Table 4.8 Main findings of econometric analyses: drought- and heat-tolerant seeds

Analysis	Main findings	Interpretation
DiD analysis	• No significant impact on indicators	N/A
OLS model	• Robust and consistent results across all indicators: 34% increase in crop income, 18% increase in gross income, 36% reduction in crop income variability, and 14.6% reduction in gross income variability (similar for heat-tolerant) • Reduces probability of poverty and food insecurity	• These results suggest a strong positive benefit to supporting improved access to drought tolerant varieties to smallholders in Zambia
Climate sensitivity	• As expected, significant positive impact under dry conditions; surprisingly also under wet conditions	• Drought- and heat-tolerant seeds also do better than non-drought tolerant seed under wet conditions

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of results of statistical analyses; detailed results are in Appendix C.3.

4.9 Findings: Analysis of Crop Diversification

Crop diversification promises higher incomes and resilience under both dry and wet climate conditions. Crop diversification—as measured by the Gini-Simpson's Index, which takes into consideration the number of different crops in a crop system as well as the share of total area dedicated to different crops—can be expected to yield strong benefits in terms of both income and—in the long term—also resilience (see Table 4.9). Crop diversification is found to have strong positive benefits under both dry and wet conditions, which suggests it is a broadly beneficial strategy across Zambia's diverse agroecological conditions.

Crop diversification is thought to have beneficial effects on nutrition. A key outcome is the diversification of on-farm diets and products available in local markets. Poor households can adopt diversification strategies if supported to access inputs, specifically seeds. In addition, new employment and investment opportunities are expected, including in assembly, processing, retailing, and export.

Table 4.9 Main findings of econometric analyses: Crop diversification

Analysis	Main findings	Interpretation
DiD analysis	• Positive impact on crop income and household income but not on income variability	• One possibility is that farmers diversify out of low-value staples, such as maize, into higher value crops, which exerts a positive effect on incomes
OLS model	• Strong, positive effect on crop and household income, and reduced income variability	• In the long term, reducing income variability also boosts resilience
Climate sensitivity	• Strong positive benefits under both dry and wet conditions	• Helps to improve household resilience to weather shocks, across Zambia's diverse agroecological conditions
Impact on rural development indicators	• Positive effects on job creation and value chain development • Expected to boost nutrition by contributing to a more diverse diet	• New job and investment opportunities are created in crop assembly, processing, retailing, and export sectors

Source: FAO, using RALS 2012 and 2015 data
Note: Summary of statistically significant results of econometric analyses; see Appendix C.3 for detailed results.

Section

5

Analysis Results: Impacts of CSA on Agriculture Sector Performance Under Climate Change

Section summary

This section addresses the feasibility, with or without widespread CSA adoption, of achieving the vision and related targets for Zambia's agriculture sector by 2050 under two scenarios: the absence of climate change, that is, business as usual (BAU); and under climate change projections. Key findings include:

- Under climate change projections, **crop yields** of several crops are projected to decline. Even without climate change, the agriculture sector target of doubling crop yields in 2050 is not achieved using conventional farming practices. CSA practices can narrow the gap to the target yield but not enough to meet the goal. Under climate change the impact of CSA on crop yields varies: for instance, drought-tolerant maize, conservation agriculture or crop diversification can enhance an already positive yield effect; other CSA practices might cause crop yields to decrease compared to conventional practices.
- Crop **production** is expected to double in 2050 compared to 2009-2011 average, even under climate change projections. CSA has the potential to increase total crop production by on average 3 percent, in the case of residue retention, up to as much as 13 percent with strategies to reduced post-harvest loss. Ruminant livestock production is expected to increase by as much as 229 percent due to improved feeding efficiency, rather than an expanded livestock population.
- Increases in agricultural production are reflected in **food availability**. Under BAU, the lower target of the calorie availability range is within reach. CSA practices such as post-harvest loss and conservation agriculture increase food security further, even under climate change projections.
- For maize and millet (and cassava under extreme climate change projections), the target of doubling **net exports** by 2050 is feasible. Reducing post-harvest losses can enhance net exports of cassava, millet and maize; promoting crop diversification could allow Zambia to become a net exporter of groundnuts.
- Increased agricultural production tracks closely with yield increases but may also be a result of **land conversion** from forest land and other natural land to cropland (approximately 917,000 ha) and grassland (in total 2.2 million ha), just short of the target to convert no more than 0.9 million ha into cropland. Results under climate change projections are similar. CSA practices don't have a significant impact on land conversion, and at a maximum spare 113,000 ha of forest land from clearance. Land use dynamics result in land conversion to grassland in a similar extent. *(continued)*

- **Greenhouse gas emissions** are projected to triple by 2050 and increase further under climate change projections. Zambia risks failing to meet its goals under NDC. CSA offers limited scope to reduce land conversion and only limited potential, even in the case of adoption of minimum soil disturbance and post-harvest loss, to reduce GHG emissions arising from fertilizer use. However, if soil carbon sequestration is taken into consideration, CSA's positive climate mitigation impacts could be many times higher (see Box 5.1).
- While the impact of CSA on land conversion is small in terms of hectarage, the **value of GHG mitigation** to society is substantial and, if valued at a shadow price of carbon, could enhance the economic net present value of an investment by between 171 and 341 percent.
- The introduction of a **carbon tax on emissions** produced from land use change has the potential to halt deforestation for agricultural production, because land conversion is insufficiently profitable. Such a tax could reduce emissions from land use change by as much as 99 percent. Cropland would likely continue to expand but to a lesser extent, limiting the negative effects on production output and calorie availability, in the range of a 2 percent decrease compared to case without a carbon tax.

This section concludes with three recommendations in support of adopting CSA practices

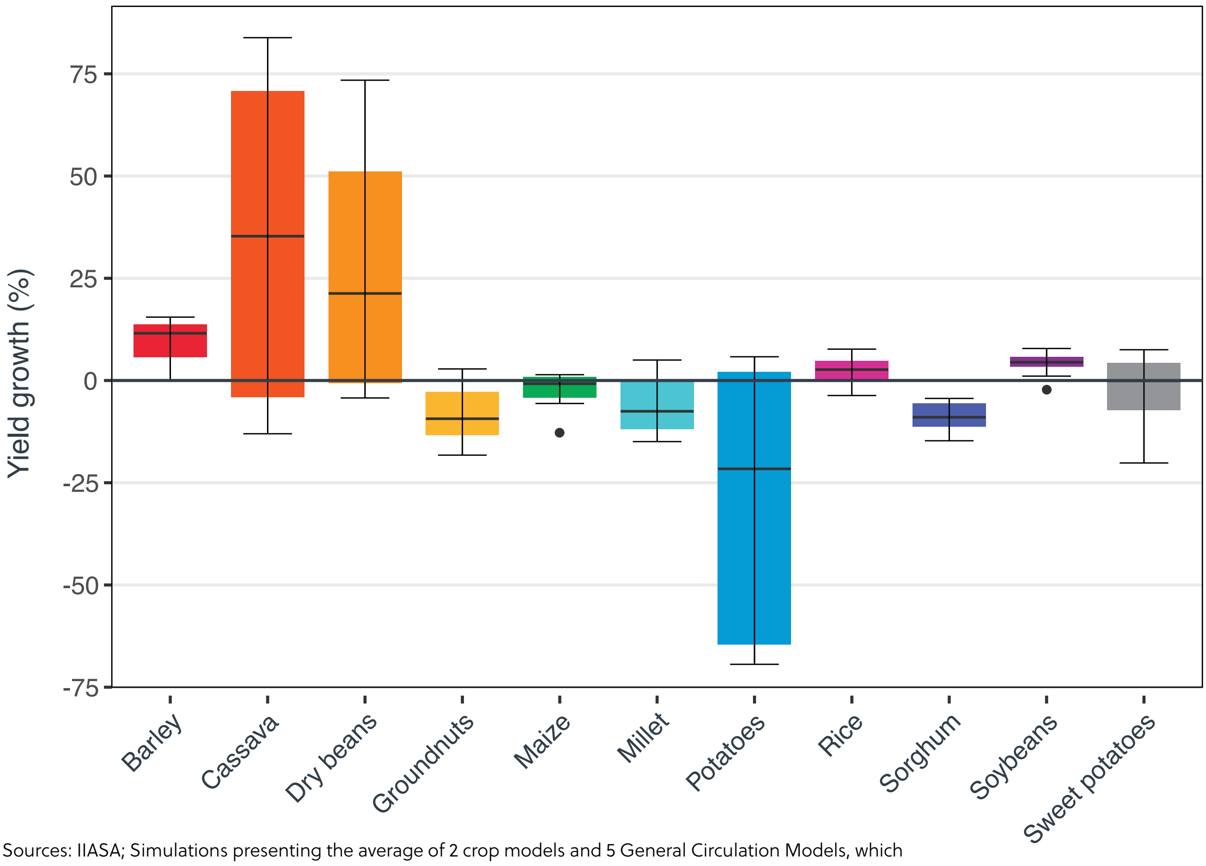
1. Investment in productivity-enhancing technologies will be necessary to further close the yield gap. Investments should strengthen agricultural research and development and dissemination of findings; support the optimal application of production inputs; introduce soil testing; facilitate access to improved seeds through rollout of local seed multiplication systems.
2. To moderate the pace of land use change, use a holistic approach to CSA that factors in externalities beyond the field level related to deforestation and land use change to avoid cropland expansion.
3. Coordinate and harmonize policy across sectors including livestock, forestry, water, and energy which is conducive to enhance impact.

This section presents results of key agriculture sector indicators for a number of CSA practices in both a future without climate change (business as usual) and for climate change projections. Indicators include: crop yield, crop production, livestock production, land use change, food availability, agricultural trade, and GHG emissions. The section examines the impact of CSA strategies and their feasibility in achieving the normative vision for Zambia's agriculture sector that is set out in Section 2. Key indicators are presented for both a BAU scenario without climate change and for climate change scenarios. Indicators are provided also in graphic form (see Figures 5.1-5.17). Error bars indicate the range of results of climate change projections. Also see Appendix E.1 for assumptions on how CSA impacts are modelled, and for projected adoption rates of CSA practices in 2050. Smallholder adoption rates in 2050 were determined through stakeholder consultations and a literature review, and range from 30 percent for conservation agriculture to 70 percent for adoption of improved seeds. CSA strategies under assessment are: agroforestry (af), conservation agriculture (ca), residue retention (rr), minimum soil disturbance (msd), drought-tolerant maize (dtm), reduction of post-harvest losses (phl), crop diversification (div). See Appendix E.2 for detailed results.

5.1 Crop Yield

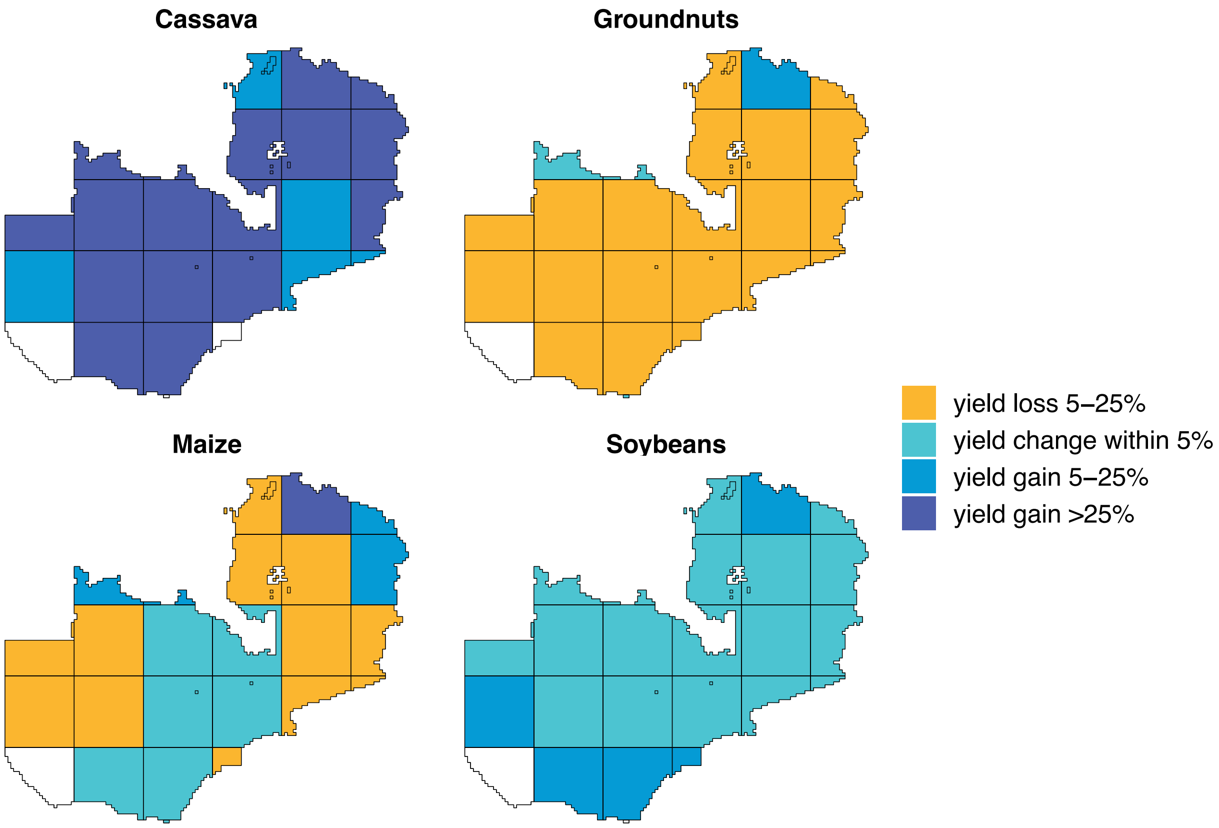
While climate change is expected to contribute to negative yield shocks for several crops, crop yields of a range of crops are also projected to increase. The impact of climate change on crop yields are assessed with two crop models and 5 General Circulation Models (GCM). Figure 5.1 presents simulations of average change in crop yield for a selection of subsistence crops for the 2010-2050 period. Climate change is expected to contribute to a negative yield shock (represented by a median value lower than zero) for six crops: groundnuts, maize, millet, potatoes, sorghum and sweet potatoes, whereas the yield effect is positive for barley, dry beans, cassava, rice and soybeans. Figure 5.2 shows the geographical distribution of the yield shock for Zambia's four most important crops. Maize is mostly produced in the Eastern Province, where yield loss is expected to be between

Figure 5.1 Changes in crop yields of several crops due to climate change between 2010-2050, in %



Sources: IIASA; Simulations presenting the average of 2 crop models and 5 General Circulation Models, which model climate change trajectories, using area harvested in 2000 as weights. Data are for subsistence farming systems.

Figure 5.2 Changes in crop yields of key crops due to climate change across Zambia, between 2010-2050, in %



Sources: IIASA; Crop models simulations presenting the average of 2 crop models and 5 GCMs, using area harvested in 2000 as weights. Data are for subsistence farming systems. No data is available for the white areas.

5 percent and 25 percent. In the Northern Province, where maize production is limited by the high acidity of the soils, climate change offers potential yield gains. For the other three crops, potential yield change is more evenly distributed over the country. Groundnut yields are projected to decrease in all areas of the country).

The goal of doubling yields by 2050 seems infeasible even in a scenario without climate change. In such a BAU scenario, crop yields are projected to increase between 14-88 percent. In a BAU scenario, maize yields are expected to increase by 88 percent between 2010 and 2050, reaching 3.9 MT/ha in 2050. This is comparable to findings from Kanyanga et al. (2013), projecting maize yields in the range of 3 MT/ha in 2050. Yields of cassava are projected to increase by 33 percent, of groundnuts by almost 35 percent, and millet by 15 percent compared to yields in 2010. Under climate change, cassava yields are likelier to increase than decrease, while the reverse is true for the other three crops (see Figure 5.3). In the most extreme climate change scenario, maize yields are projected to be 15 percent lower, at 3.3 MT/ha than under BAU. The target of doubling maize productivity from average 2009 and 2011 levels, as set out in the agriculture sector vision, is not achieved. In a scenario without climate change, the gap towards the target yield is smallest for maize, followed by cassava. Under climate change, cassava could potentially achieve the goals set out in the vision.

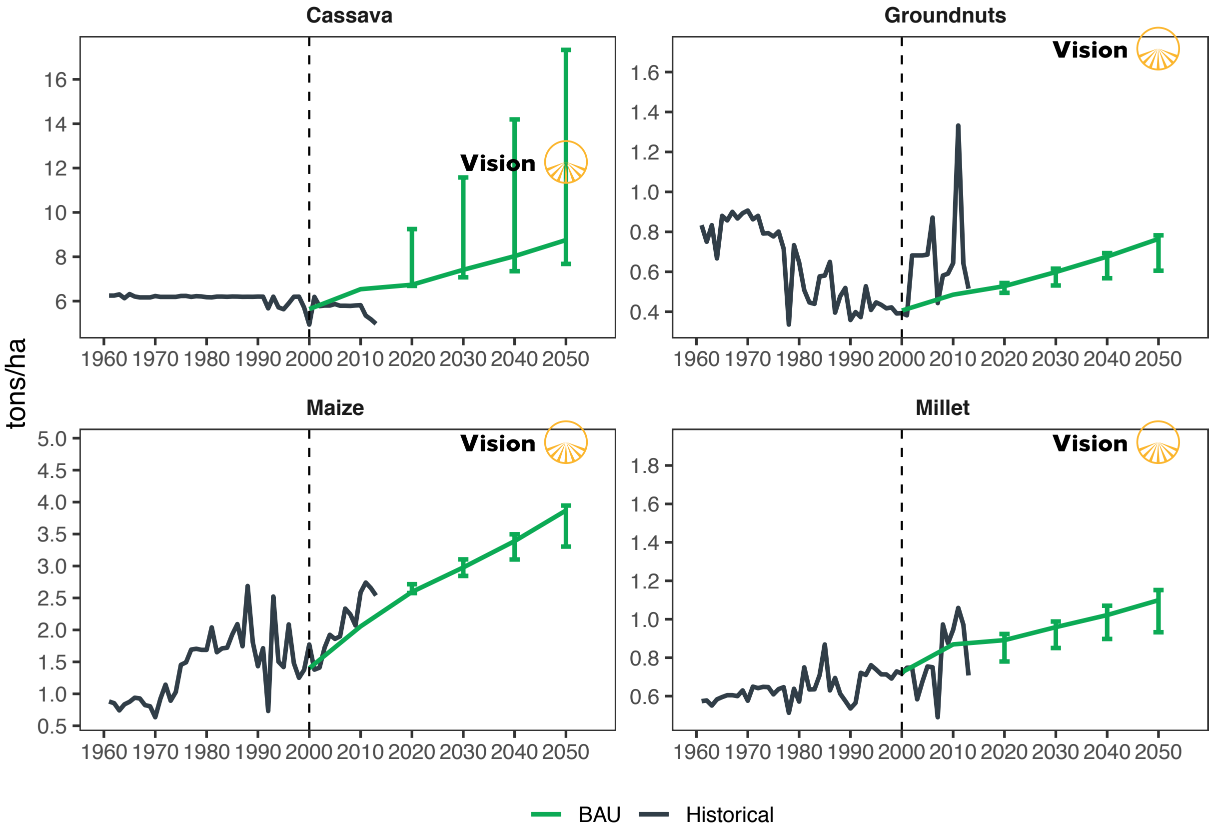
CSA practices have the potential to narrow the gap towards target yields and toward achieving the agriculture sector vision, but cannot close the gap. For maize, strategies to reduce post-harvest loss offer the potential to boost production per hectare by 23 percent (see Figure 5.4), from 3.9 MT/ha to 4.8 MT/ha, which approaches the vision target of 4.9 MT/ha. This is followed by: conservation agriculture, which could increase maize yields by around 14 percent over conventional practices; agroforestry (12 percent); minimum soil disturbance (9 percent); and residue retention (4 percent). For cotton, groundnuts, and soybeans, minimum soil disturbance offers the largest positive impact. Under the climate change projections, CSA practices show sensitivity to climate change but still outperform conventional practices in terms of yield gains. Drought-tolerant maize varieties show potential gains of as much as 8 percent; and adoption of conservation agriculture may potentially enhance the positive effects of climate change on soybean yields. The CSA practices that lead to the most pronounced yield reductions are minimum soil disturbance in cassava production systems, residue retention in soybean production and diversification in maize systems. This is due to the expansion of these crops into less productive areas which are expected to reduce the overall average yield.[6]

5.2 Crop Production

Total crop production is projected to double to around 6.5 million tons of dry matter by 2050 even with conventional farming practices. Crop production in Zambia is driven by changes in domestic and foreign demand as well as supply side factors. Maize continues to be the dominant crop, with production likely to increase by 200 percent over 2010 levels (see Figure 5.5). Increased production of several other crops is projected to be more gradual and reflective of historical trends through 2010. This implies that without targeted interventions, the agriculture sector vision of increasing crop diversification may not be achieved. Considering climate change projections, total crop production could vary from an -11 percent decrease to an increase of up to 20 percent over levels under BAU. Although crop production is projected to double, crop yields are not projected to double, which suggests that a share of production increases can be attributed to the expansion of land for agricultural production.

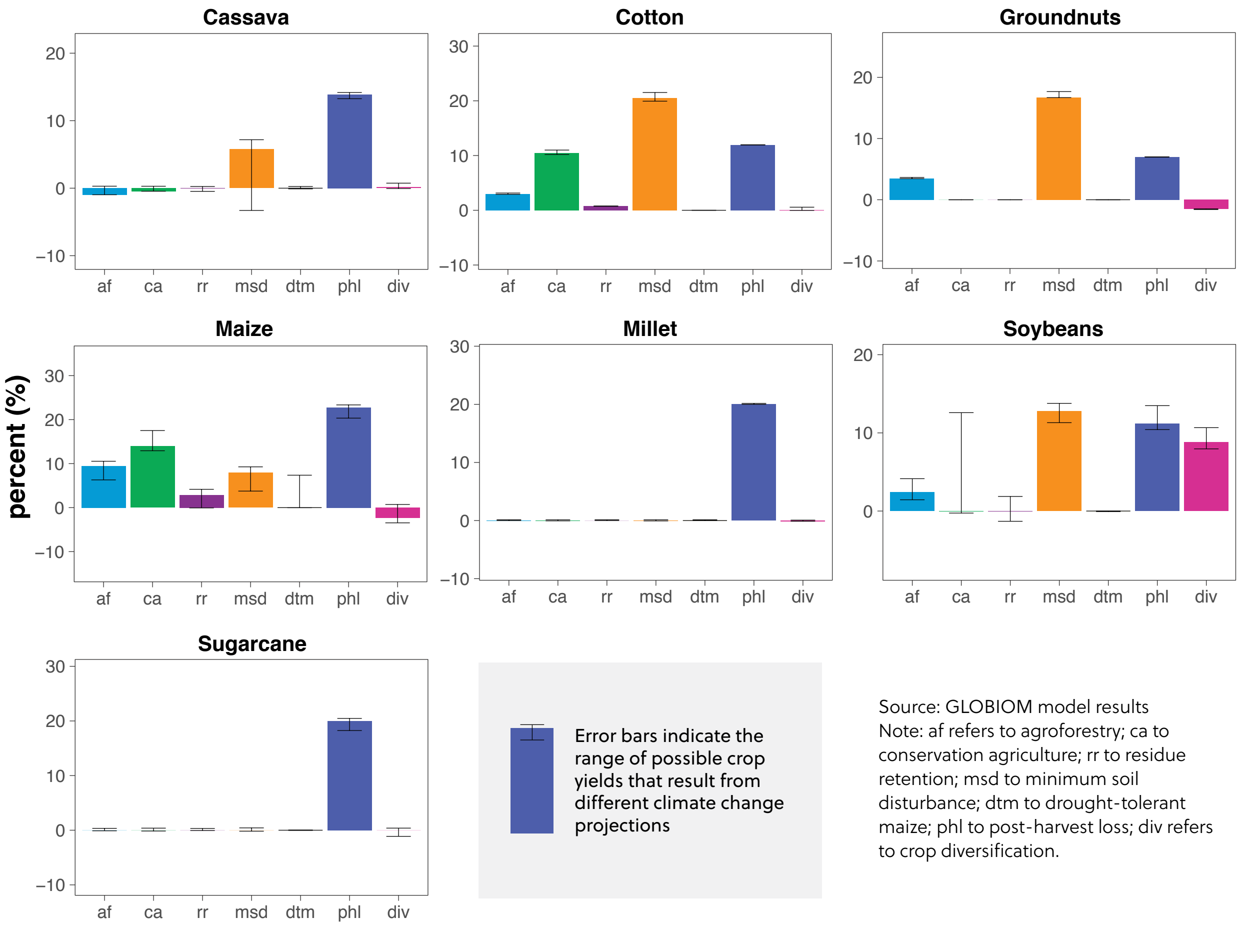
Even under climate change projections, CSA promises increased crop production over results from conventional practices. In a BAU scenario, reduction of post-harvest losses, which is modelled for most crops, offers a potential increase in total production of as much as 13 percent; next highest

Figure 5.3 Trends in crop yields under conventional practices until 2050, for projections without and with climate change (error bars)



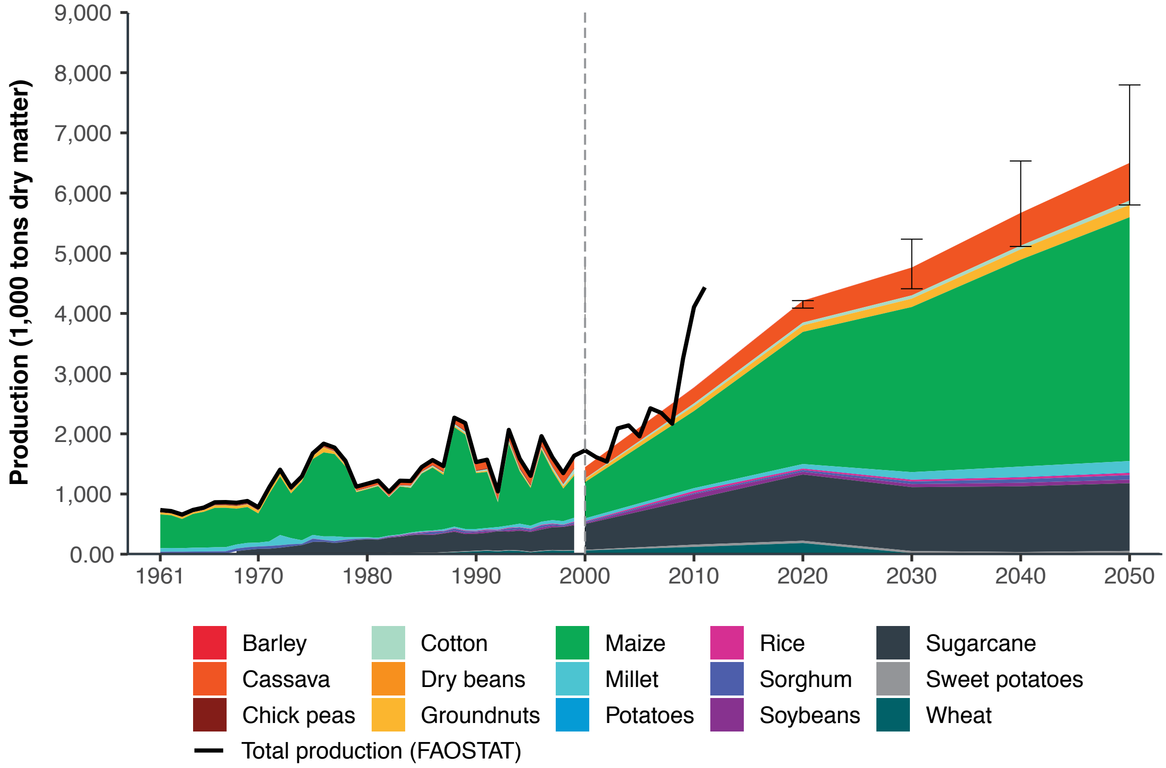
Sources: Historical values are from FAOSTAT; GLOBIOM provides projections from 2000-2050 for scenarios without and with climate change; "Vision" was determined through stakeholder consultation and represents the targets for agriculture sector development in 2050.
Note: Error bars indicate the range in crop yield for different climate change projections.

Figure 5.4 Changes in crop yields under CSA, in %, as compared to conventional practices in 2050



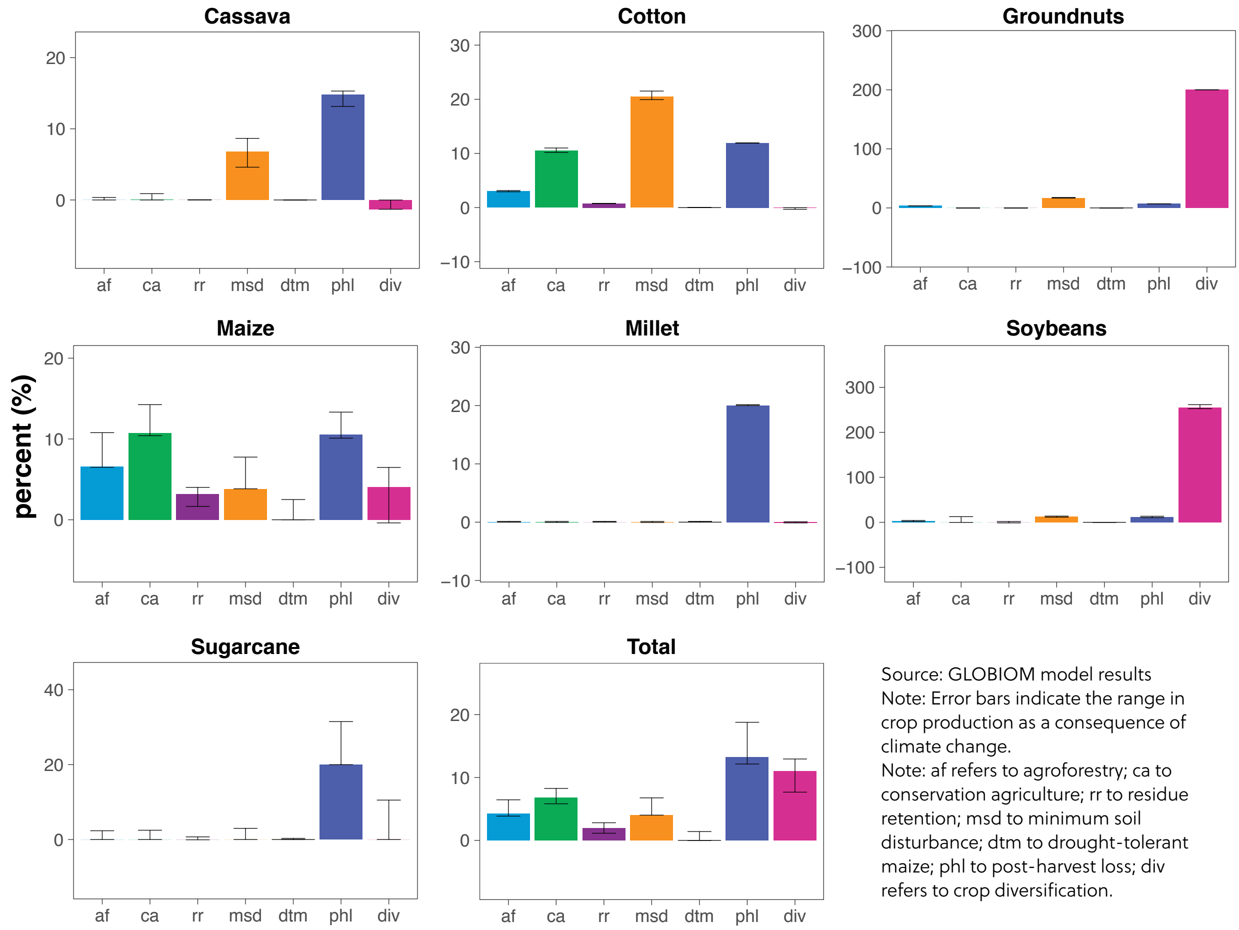
Source: GLOBIOM model results
Note: af refers to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

Figure 5.5 Trends in crop production under conventional practices until 2050, for projections without and with climate change (error bars)



Sources: Historical values are from FAOSTAT; GLOBIOM provides projections from 2000-2050 for scenarios without and with climate change.
Note: Error bars indicate the range in total crop production as a consequence of climate change.

Figure 5.6 Changes in crop production under CSA, in %, as compared to conventional practices, in 2050



Source: GLOBIOM model results
Note: Error bars indicate the range in crop production as a consequence of climate change.
Note: af refers to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

is crop diversification at 11 percent followed by: conservation agriculture (7 percent); minimum soil disturbance and agroforestry (both 4 percent); and residue retention (3 percent). There are notable variations between crops: adopting crop diversification has the potential to boost groundnut and soybean production by as much as 200 percent. Whereas conservation agriculture and minimum soil disturbance might increase maize and cotton production by around 10 percent and 5-20 percent, respectively compared to conventional practices. Climate change projections confirm that CSA has a positive impact on total production, an effect that could be enhanced by reducing post-harvest losses, and adopting agroforestry and minimum soil disturbance. Crop diversification away from maize seems to have a rather negative effect under climate, driven by declines in maize production (see Figure 5.6).

5.3 Livestock Production and Head of Livestock

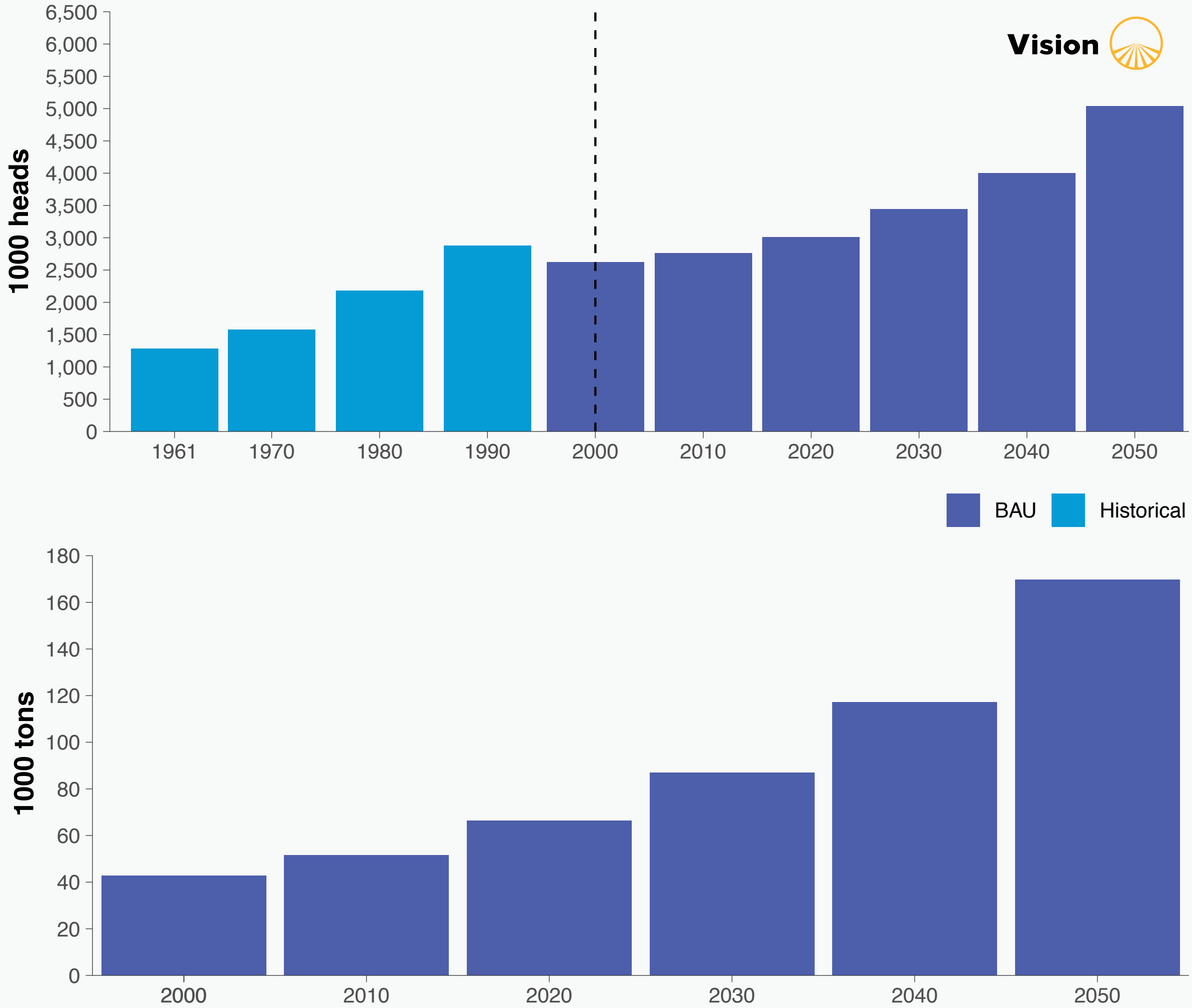
The goal included in the 2050 vision and agriculture sector targets to expand livestock herds to 6,000,000 head does not appear to be feasible, but improvements in feeding efficiencies which result in increased meat production offer gains nevertheless. In a business as usual scenario, cattle numbers are projected to increase 82 percent, from 2.6 million to 5 million head between 2010 and 2050, a significant rise although one that falls short of vision targets (see Figure 5.7). Measuring the development of the livestock sector by a cattle headcount provides at best a partial picture. Increases in feeding efficiency will result over time in livestock units that produce more output in the form of milk, eggs, and meat. Herrero et al. (2014) estimate that feed conversion efficiencies in sub-Saharan Africa could increase by 50 percent over the next 40 years (under a "Middle of the Road" SSP2 scenario). Figure 5.7 shows an increase in ruminant meat production between 2010 and 2050 of roughly 229 percent, stemming mainly from increased feeding efficiencies. The more than twofold projected increase in total production represents a strong improvement. Dairy production is expected to increase by more than 387 percent.

5.4 Land Use Change

Through 2050, cropland area is projected to expand in the southern and southwestern regions of Zambia, at the expense of 0.9 million ha of mainly forest area since 2010. In 2010, 65 percent of the total land cover of Zambia consisted of forested area; agricultural land accounted for over 30 percent of the total land cover, of which only 2 percent was cropland. Under BAU, cropland area is projected to expand by almost 917,000 ha, with total agricultural land (cropland and grassland) growing by almost 2.2 million ha. Most of the new agricultural land will be formerly forested areas and natural land, reducing the country's total forest area by 7 percent. Land conversion is projected to occur mostly in the Southern Province and Western Province, which fall within AEZ I and AEZ IIa, and have suitable soil and climate conditions for maize production. The projected growth in cropland is almost in line with the goal contained in the vision of converting no more than 0.9 million ha of land for agricultural purposes, but at odds with the goals set out in the National Policy on Environment, which aims at a zero increase in agricultural land. Figure 5.8 shows land use patterns over time and Figure APP 9 a-d (see Appendix E.2) provides a spatial representation. Projections under climate change scenarios hardly differ from those in the BAU scenario (see Figure 5.9).

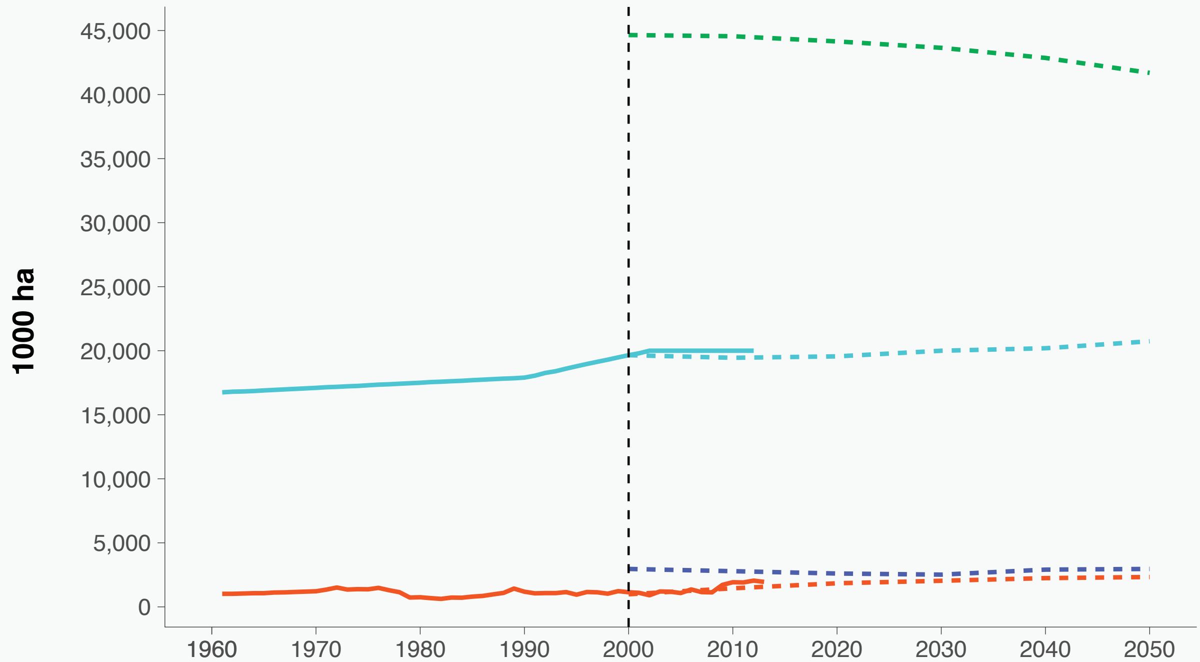
Following CSA adoption, increased crop yields tend to mean slower cropland expansion. The yield gains associated with the adoption of different CSA practices correspond with a avoided cropland conversion ranging from between 32,000 ha in the case of conservation agriculture and 43,000 ha in the case of minimum soil disturbance to 113,000 ha in the case of reducing post-harvest losses. For residue retention, cropland growth seems to increase by an additional 4,000 ha, the adoption of crop diversification and legume production results in a 700,000 ha increase in cropland, largely

Figure 5.7 Number of livestock heads (above) and ruminant meat production (below) until 2050



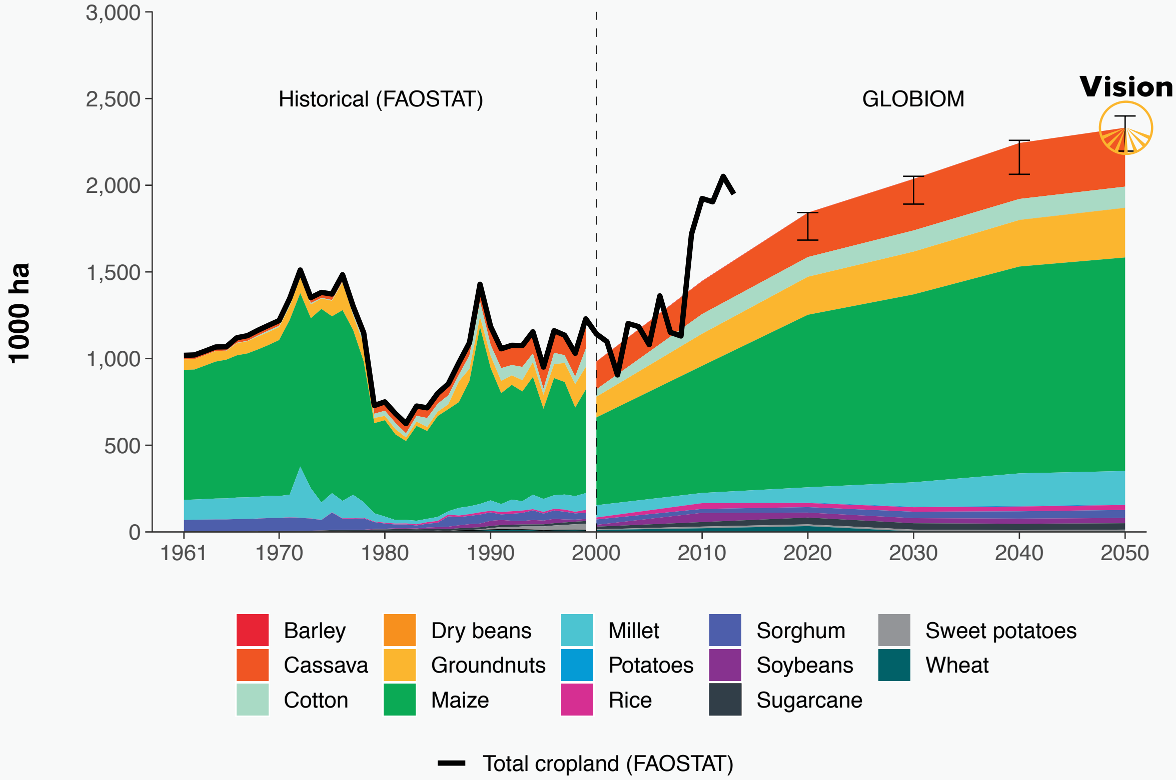
Sources: Historical values are from FAOSTAT; GLOBIOM provides projections from 2000-2050; vision was determined through stakeholder and policy consultation and indicates a target for agriculture sector development in 2050.

Figure 5.8 Trends in land use under conventional practices, 1960-2050, for projections without climate change



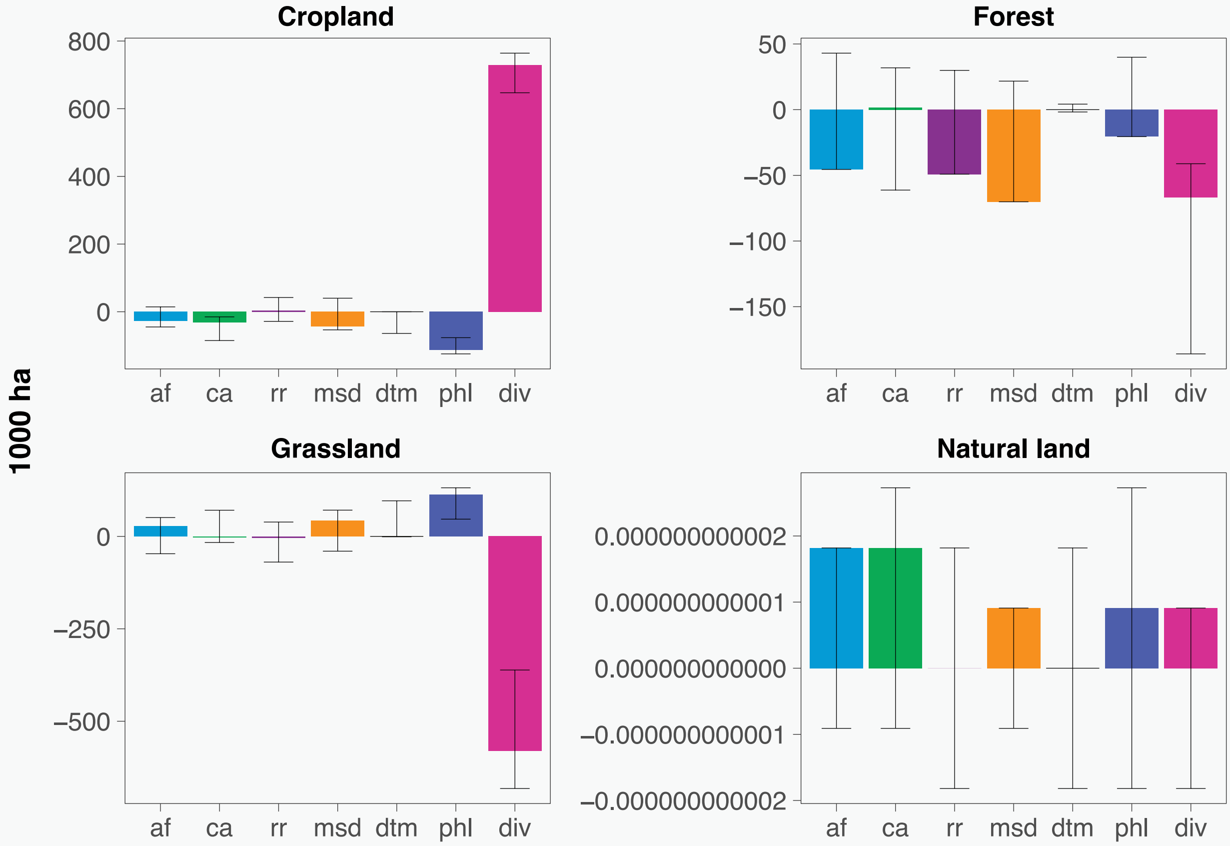
Sources: Historical values are from FAOSTAT, where available; GLOBIOM provides projections from 2000-2050
Note: Historical data for forest and natural land are not available.

Figure 5.9 Changes in cropland until 2050, under conventional practices, for projections without and with climate change (error bars)



Sources: Historical values are from FAOSTAT; GLOBIOM provides projections from 2000-2050 for scenarios without and with climate change; the vision was determined during stakeholder workshop and indicates a target for agriculture sector development in 2050.
Note: Total cropland excludes a number of crops (e.g., vegetables and fruits) for which total land use is small and cannot be modelled with GLOBIOM. Error bars indicate the range in total cropland as a consequence of climate change.

Figure 5.10 Changes in land use due to CSA adoption, in 1000 ha, as compared to conventional practices, in 2050



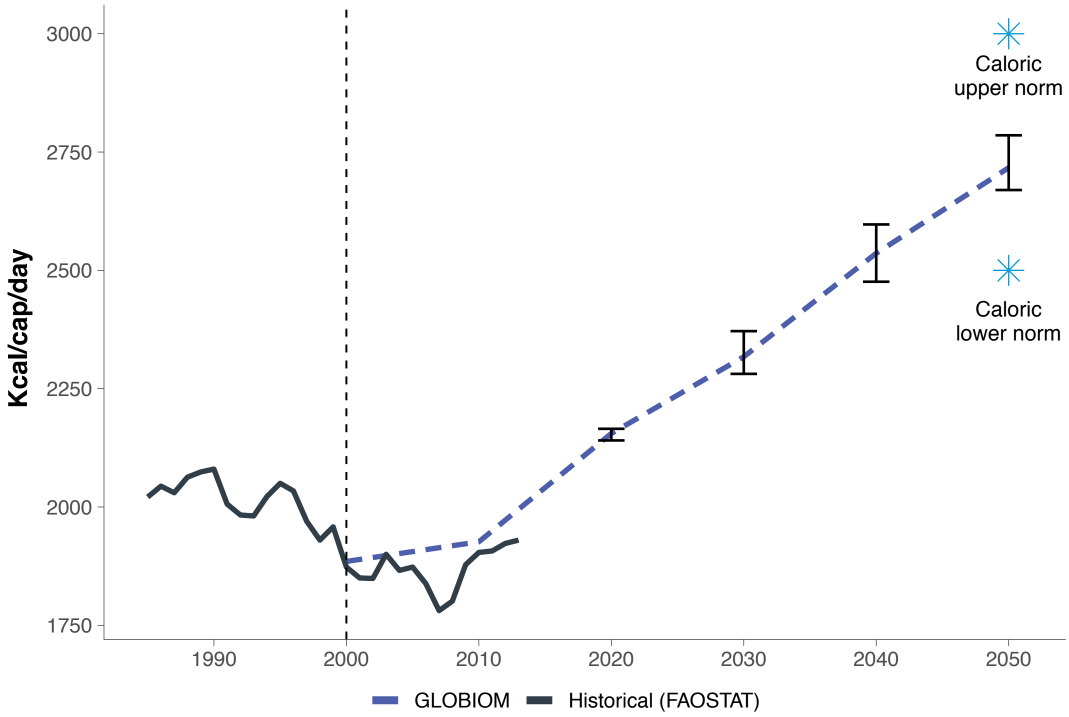
Source: GLOBIOM model results
Note: Error bars indicate the range in total land use category as a consequence of climate change. af refers to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

converted from grassland (see Figure 5.10). Any reductions or increases in cropland are matched by a corresponding expansion or decrease in grassland and hardly any forests or other natural lands are spared. All things considered, the impacts are small in comparison to total crop and grassland under BAU (around 1-5 percent of cropland and <1 percent for grassland). The adoption of CSA practices has limited impact reducing land conversion (see Figure 5.10).

5.5 Food availability

Under BAU, caloric intake levels will rise steadily and hit the lower end of the recommended range of caloric intake in 2040 (see Figure 5.11). CSA practices are expected to increase food availability. According to FAOSTAT (2017), calorie availability in Zambia has hovered at or below 2,000 kilocalories (kcals) per capita per day since 1985.[7] In 2010, this level dropped to 1,900 calories. In the BAU scenario diets are expected to evolve in line with FAO projections (Alexandratos and Bruinsma 2012).[8] As a result, by 2050 calorie intake will have increased by 34 percent above 2010 levels, or by more than 700 kcals per day. FAO considers 2,500-3,000 kcals/capita/day a useful target for developing countries.[9] CSA practices have a small but crucial effect on reducing crop prices and therefore increasing food availability, particularly, the practice of reducing post-harvest loss, which increases food availability by 7 percent, followed by conservation agriculture at 5 percent. The total effect is smaller than the increase in agricultural production because not all food produced is for consumption (see Figure 5.11).

Figure 5.11 **Trends in calorie availability, under conventional practices, projected until 2050 without and with climate change (error bars)**

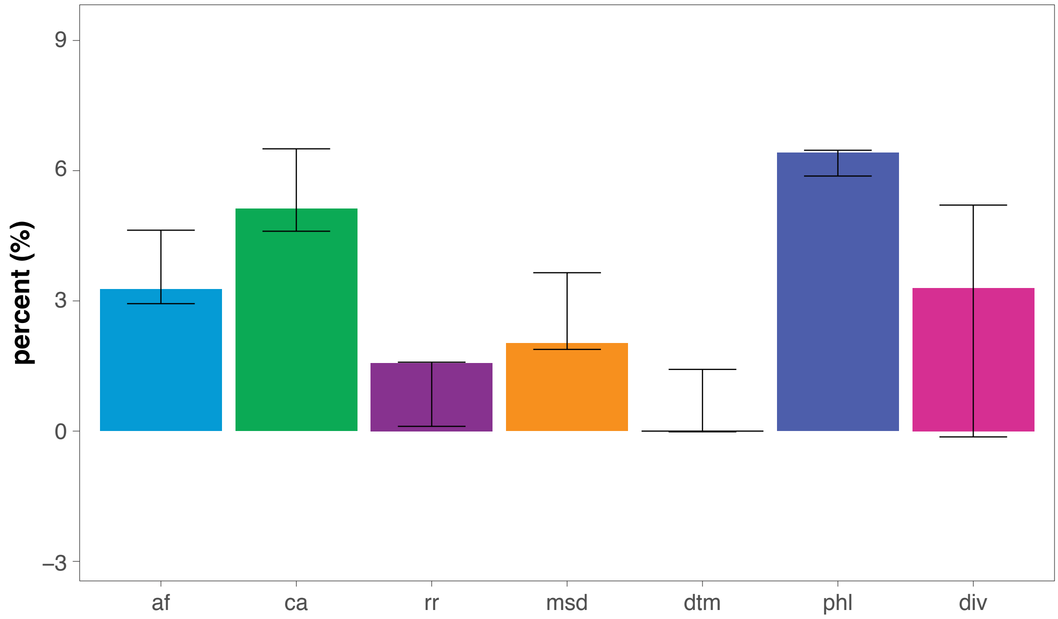


Sources: Historical values are from FAOSTAT; the GLOBIOM model provides projections from 2000-2050
Note: Error bars indicate the range in total calorie production as a consequence of climate change

5.6 Agricultural Trade

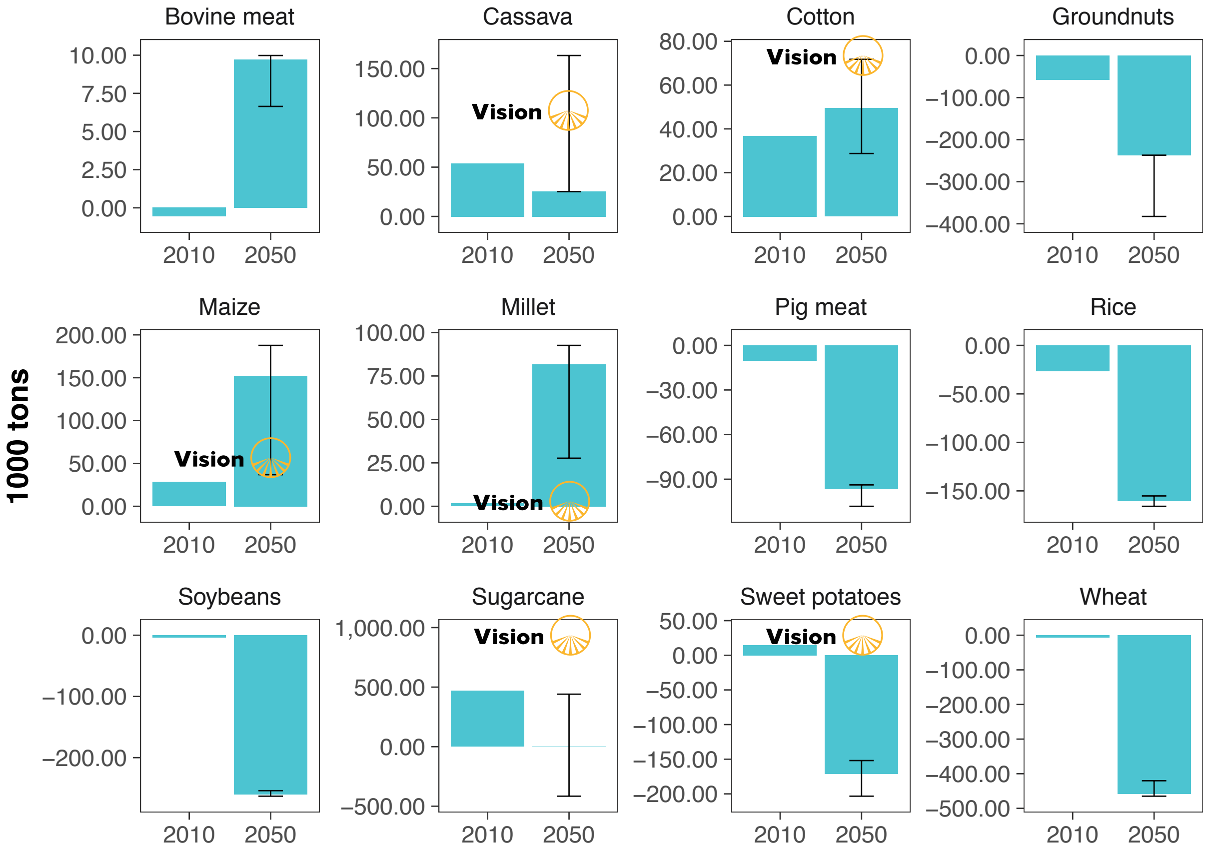
Under BAU, trade trends vary across commodities. Climate change is a strong driver of both imports and exports. Figure 5.13 shows net agricultural trade (exports minus imports) for key agricultural commodities in 2010 and 2050 as well as the sector vision target of doubling net exports

Figure 5.12 Impact of CSA on food availability in comparison to conventional practices



Sources: GLOBIOM model results
Note: Error bars indicate the range in total food availability as a consequence of climate change.

Figure 5.13 Net agricultural trade in 2010 and 2050, in 1,000 tons

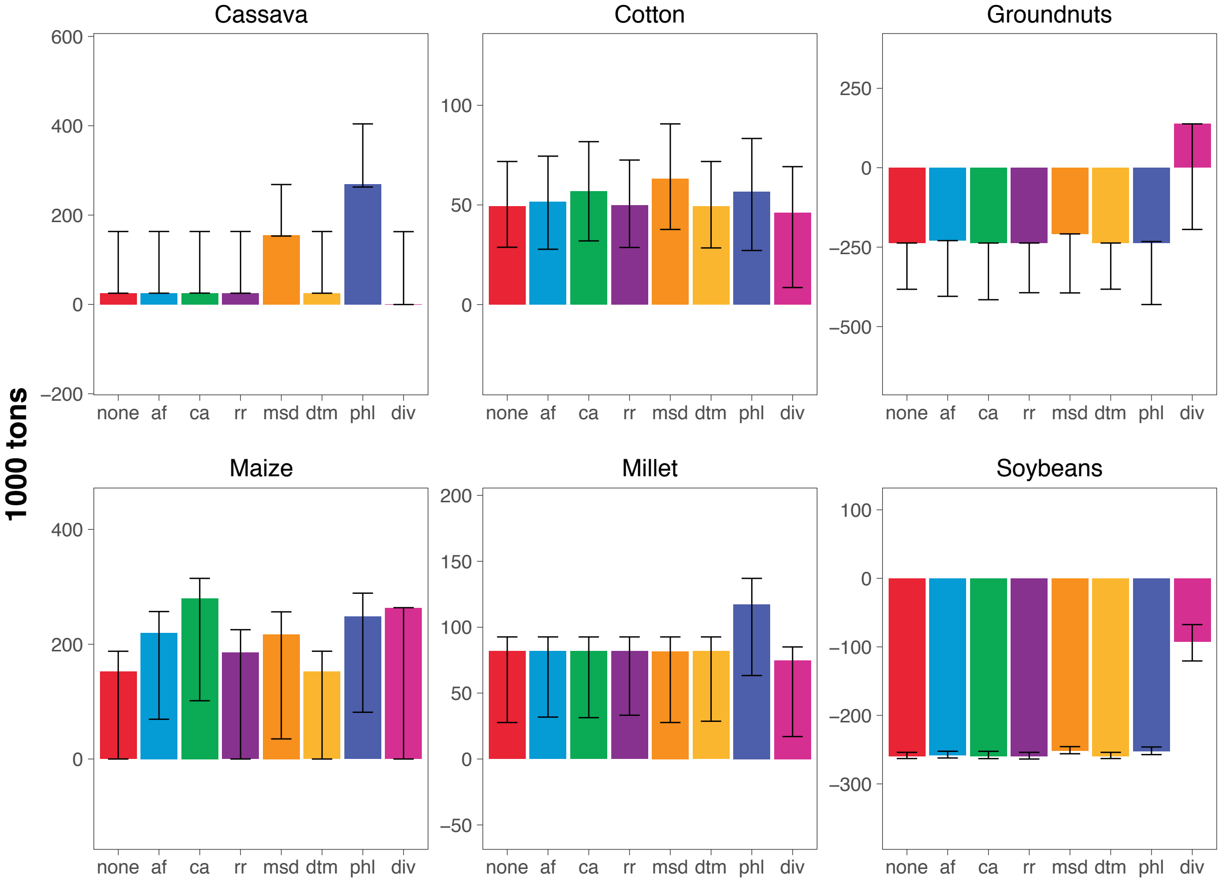


Sources: GLOBIOM model results (projections); vision was determined through policy and stakeholder consultation.
Note: Error bars indicate the range in net trade as a consequence of climate change.

in 2050. The results are mixed. For cassava, cotton, maize, and millet net trade is positive in 2010 and is expected to increase by 2050. Of these, only maize and millet are expected to achieve the vision target of doubling net trade by 2050. For cassava and sugar cane, which also show positive net trade in 2010, a decrease is projected. For beef, pork, and several crops, including groundnuts, rice, soybeans, sweet potatoes, and wheat, net imports are expected to increase. The error bars indicate that climate change could have a substantial impact on the trade balance of several crops, particularly cassava, maize, cotton, millet, and sugar cane. For cassava and cotton, net trade is projected to exceed the 2010 values under an extreme climate change scenario, and to nearly hit the vision target.

CSA is expected to increase Zambia's international competitiveness and thus reduce its trade deficit in certain commodities. Increases in crop yield can impact the international competitiveness and contributes to higher exports. Post-harvest loss, conservation agriculture, crop diversification, and minimum soil disturbance are among the driving forces of increased net exports. Notably, Zambia has the potential to become a net exporter of groundnuts and reduce net imports of soybeans, if crop diversification is promoted through a policy change in subsidies, which lowers farmers' production cost. However, these subsidies may jeopardize the net export potential of other crops (see Figure 5.14).

Figure 5.14 Effect of conventional practices and CSA on net trade in 2050, in 1000 tons

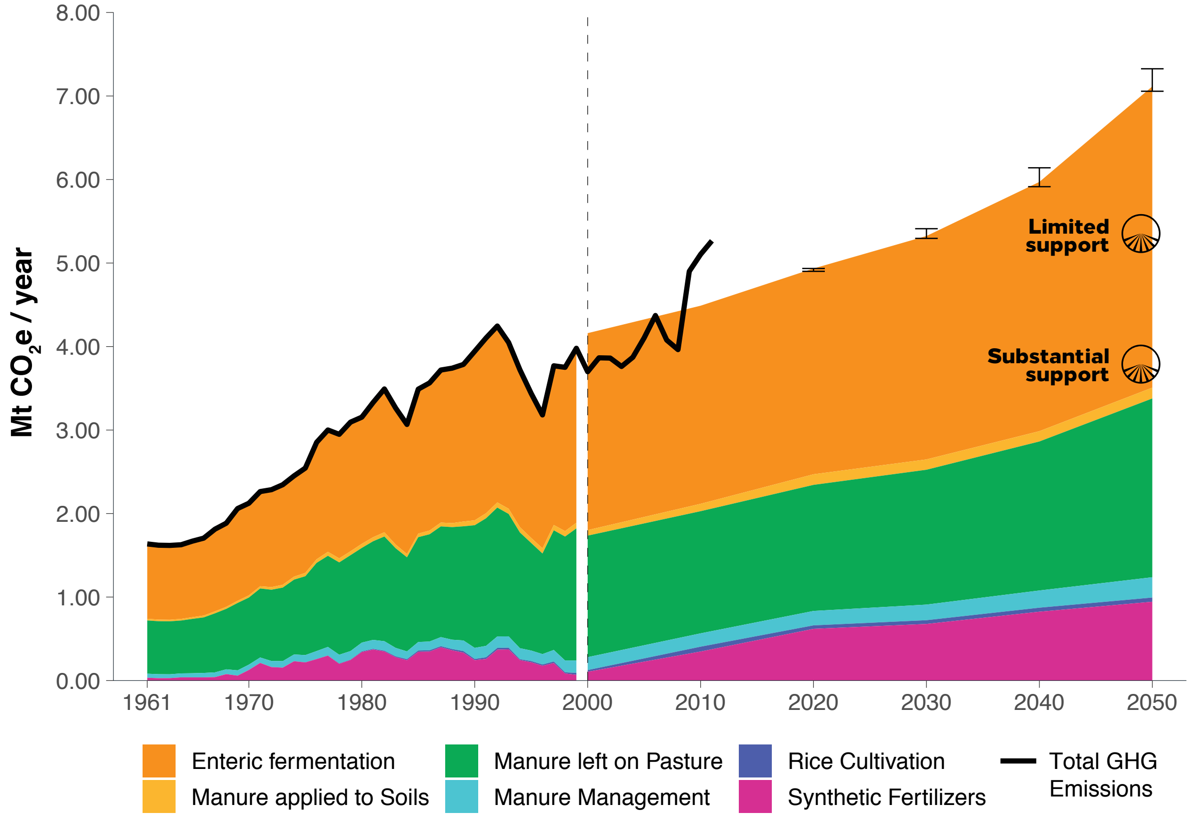


Sources: GLOBIOM provides projections from 2000-2050 for scenarios without and with climate change.
Note: Error bars indicate the range in net trade as a consequence of climate change. af refers to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

5.7 GHG Emissions

Under conventional management practices, emission reductions arising from agriculture and LULUCF will not meet Zambia's emission reduction goals as set out in the NDC. Livestock emissions are expected to increase, and emissions from fertilizer are expected to contribute a significantly larger share to agricultural emissions by 2050. The NDC suggests emission reductions of 38 $MtCO_2e$ by 2030, which is stated to translate into a reduction potential of 47 percent from the 2010 baseline, conditional on substantial international support.[10] This analysis uses the targets of reducing 25 percent, with only domestic funding, and 47 percent conditional on international support as targets for each emission category under analysis.[11] Figure 5.15 shows six sources of agricultural emissions which are accounted for in the GLOBIOM model, excluding emissions from cultivation of organic soils, or burning of savanna or crop residues. Livestock accounted for more than 92 percent of emissions in 2010, the use of synthetic fertilizers, 7.3 percent, and rice cultivation, 1.3 percent. Emissions from synthetic fertilizer are projected to increase rather than decrease, to more than 13 percent in agriculture sector emission because of a shift toward more intensive crop production systems. Emissions from livestock are expected to increase steadily, reflecting expanding livestock herds (see Section 5.3). Under climate change, as indicated by the error bars in Figure 5.15, emissions are expected to increase by up to 3 percent (Figure 5.15).

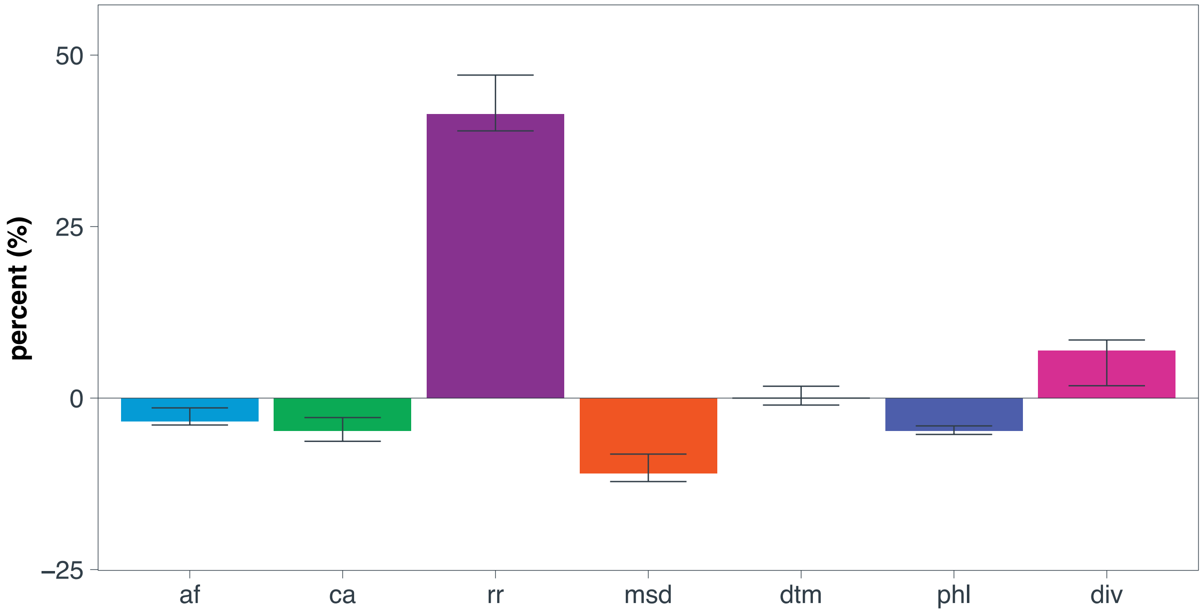
Figure 5.15 **Trends in agricultural GHG emissions until 2050, under conventional practices, projected without and with climate change (error bars)**



Source: Historical values are from FAOSTAT; the GLOBIOM model provides projections from 2000-2050 for scenarios without and with climate change.
Note: Limited and substantial support indicate NDC goals. Error bars indicate the range in total emissions as a consequence of climate change.

Minimum soil disturbance and reduced post-harvest losses are key abatement strategies to enhance the mitigation effect of synthetic fertilizers, but considered individually, are not sufficient to achieve the NDC emissions targets. See Box 5.1 for an overview of the impact of CSA adoption on GHG emission reductions. The GLOBIOM results focus on the impact of CSA on synthetic fertilizer. Figure 5.16 indicates that expanded use of minimum soil disturbance and reduction of post-harvest losses contributes to 11 percent and 5 percent decrease in emissions from synthetic fertilizer,

Figure 5.16 Effect of CSA adoption on GHG emissions from synthetic fertilizer as compared to conventional practices, in %, in 2050



Sources: GLOBIOM model results
Note: Error bars indicate the range in emissions as a consequence of climate change. af refers to agroforestry; ca to conservation agriculture; rr to residue retention; msd to minimum soil disturbance; dtm to drought-tolerant maize; phl to post-harvest loss; div refers to crop diversification.

respectively, as compared to conventional practices. Adoption of post-harvest loss has an indirect impact: increased available production quantities leads to less expansion of cropland, which in turn cuts demand for nitrogen fertilizers. Taken individually, the impacts from adopting post-harvest loss and minimum soil disturbance are insufficient to meet the NDC target of reducing GHG emissions by between 25 and 47 percent for the synthetic fertilizer category. Expanding residue retention and implementing crop diversification policies will bring about respective increases in GHG emissions of 39 percent and 7 percent. However, GLOBIOM underestimates the GHG mitigation impact for CSA practices by failing to factor in their soil carbon sequestration potential (see Box 5.1; also Smith et al. 2008 and Corsi et al. 2012).

Deforestation remains a major driver of GHG emissions through 2050, a trend that significantly hampers achievement of Zambia's NDC emission reductions targets. GHG emissions from LULUCF–excluding biomass burning–are projected to almost triple from around 6.4 $MtCO_2e$ in 2010 to 37 $MtCO_2e$ in 2050 (see Figure 5.17), mainly as a result of land conversion from forest to cropland and grassland. This suggests that emission reduction goals of between 25 percent and 47 percent are not feasible. Under climate change projections, emissions from land use change and deforestation may increase even further. While some CSA practices are expected to slow the expansion of cropland (see Section 5.4), the positive effects of these on emission reduction may be outweighed by increased land conversion to grassland. Overall, CSA adoption can reduce emissions from land use change, but only by on average -0.32 percent compared to conventional practices.

5.8 Policy Scenario: Impact of Carbon Tax to Curb Land Use Change

This section explores the impact of introducing a carbon tax for emissions resulting from deforestation and conversion of natural land for agricultural production. Land use change is a notable contributor to carbon emissions associated with Zambia's agriculture sector, and presents an obstacle to the country meeting its NDC targets. We explore the impact of a range of carbon prices

Box 5.1 Potential impact of CSA on soil carbon sequestration

The impact of CSA strategies on climate mitigation derives from:

- ***Increasing the GHG emission intensity*** of a product, which can be calculated per hectare or per unit produced, that is, tCO_2e emissions per unit of product produced for selected agricultural commodities. An increase in GHG intensity implies a more positive environmental impact per unit of product. This can be achieved by increasing application efficiency of fertilizer or enhancing the productivity of livestock by improving feeding practices and forage quality.
- ***Increasing soil carbon sequestration***, which entails increasing the amount of organic matter added to the soil from plant sources and animal waste and applying practices that reduce the decomposition of existing soil organic carbon stocks (for example, restoring degraded land; using residues to cover agricultural soil; avoiding soil disturbances) until a saturation point is reached, which typically occurs after 20 years.
- ***Reducing the rate of conversion of forest land to agricultural land*** by increasing productivity per hectare while at the same time providing incentives to reduce land conversion.
- ***Increasing biomass growth*** by introducing practices such as agroforestry, which supports the sequestration of carbon in tree biomass until the system is at full maturity.

There have been few long-term studies of soil carbon dynamics or references to soil's initial carbon stock, particularly in developing countries. Due to these data constraints, GLOBIOM cannot account for the soil carbon sequestration and biomass-growth impacts of specific CSA practices. We present additional evidence to emphasize CSA's potential to enhance soil carbon sequestration: (i) The figure below shows experimental evidence of the soil carbon sequestration impacts of several CSA practices, which has a mitigation potential of between 0.2 and 1.1 tCO_2e emission/ha. This is higher than the average emission levels occurring with conventional maize systems. (ii) The table below presents Tier 1 emission coefficients per hectare as provided by Intergovernmental Panel on Climate Change (IPCC) 2006 and the 4th Assessment Report of IPCC (Smith et al. 2007), for five management practices and two climate regimes in Zambia. Improved manure management seems to have the highest potential to enhance soil carbon sequestration. (iii) We use the tool EX-ACT, which uses Tier 1 emission coefficients, for a simple calculation examples: each practice in Table 1 is applied on 1,000 ha cropland; per hectare 50 kg synthetic fertilizer are applied instead of 100 kg. Over 20 years -112,619 tCO_2e emission, or -1.1 tCO_2e per year and per hectare, are saved. Thereof, 88 percent emission reduction are attributed to soil carbon sequestration and only 12 percent to emission reduction from reducing fertilizer.

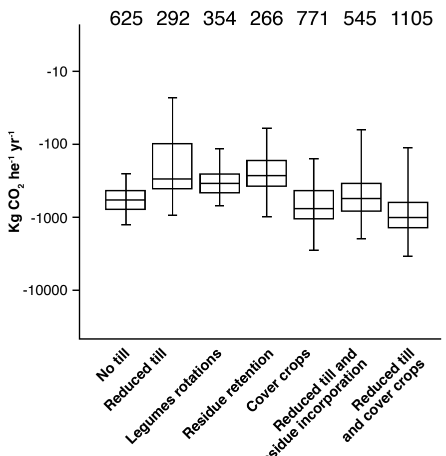
However, Tier 1 emission coefficients are highly aggregated and do not consider country-specific characteristics for soil carbon sequestration, and so need to be interpreted with caution. To improve coefficients for changes in soil organic carbon (SOC) stock and storage, disaggregated and area-specific information on previous land use, SOC stocks or SOC content and bulk densities for both the previous and current land use, soil depth, and time span since conversion are needed (Cardinael et al. 2018).

Annual emission coefficients for soil carbon sequestration, in tCO_2e

Practices/climate regime	Warm temperate and moist	Cool temperate and dry
Improved agronomic practices	0.88	0.29
Improved nutrient management practices	0.55	0.26
No tillage, residue retention	0.7	0.15
Improved water management	1.14	1.14
Improved manure application	2.79	1.54

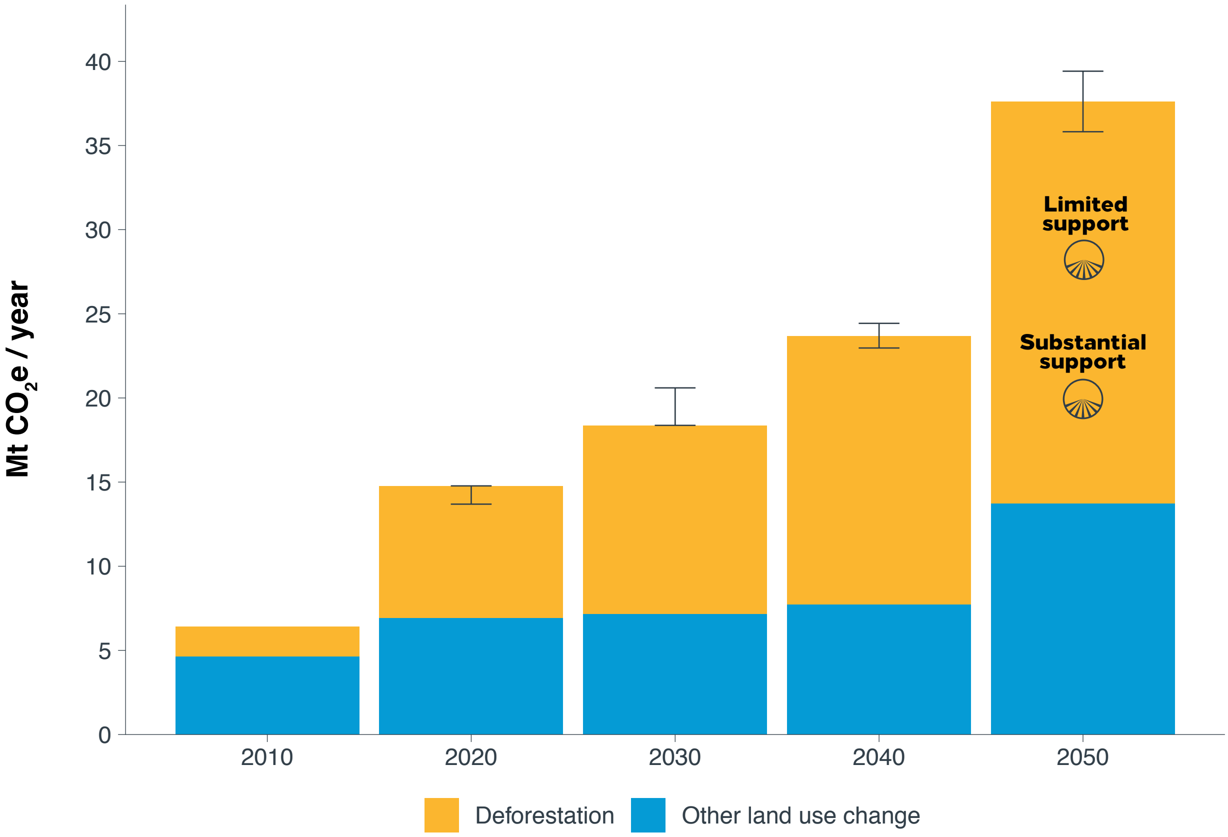
Source: FAO (2016)

Annual mean mitigation potential of CSA practices through soil carbon sequestration in Zambia



Source: FAO (2015)

Figure 5.17 LULUCF GHG emissions under conventional practices, projected until 2050 without and with climate change (error bars)



Sources: GLOBIOM model results
Note: Limited and substantial support indicate NDC goals; Error bars indicate the range in emissions as a consequence of climate change.

on land use change using two policy scenarios: (i) imposition of a carbon tax on emissions arising from conversion of any kind of land to cropland, and from the conversion of forest land to grassland; however, conversion from natural land to grassland is still possible without an emissions tax *(Crop-tax scenario)*; (ii) imposition of a carbon tax on emissions from conversion of natural land and forest to cropland and grassland; emissions from converting grassland to cropland are not taxed *(Ag-tax scenario)*. Emissions are calculated as the difference between initial and final land cover carbon stock (Kindermann et al 2008; Ruesch and Gibbs 2008; Havlik et al. 2011).[12] Three prices scenarios are used: (i) very low carbon prices (denoted *vl1,2,3*; and ranging between US$5, US$11 and US$21 per t$CO_2$e emission) that reflect the typical market price of carbon for forestry projects; (ii) the lower and higher bound of shadow prices of carbon proposed by the World Bank (2017b) (denoted *low* and *high* respectively starting at US$40 and US$80, respectively); and (iii) a high price of US$200, t$CO_2$e that Rogelj et al. (2018) and Frank et al. (2017) found may keep global warming below 1.5°C by 2100, as well as US$1 million per t$CO_2$e, to show the upper extent of the effects of a carbon tax (denoted as *vhigh* and *max*). Prices in all scenarios are assumed to increase over time.

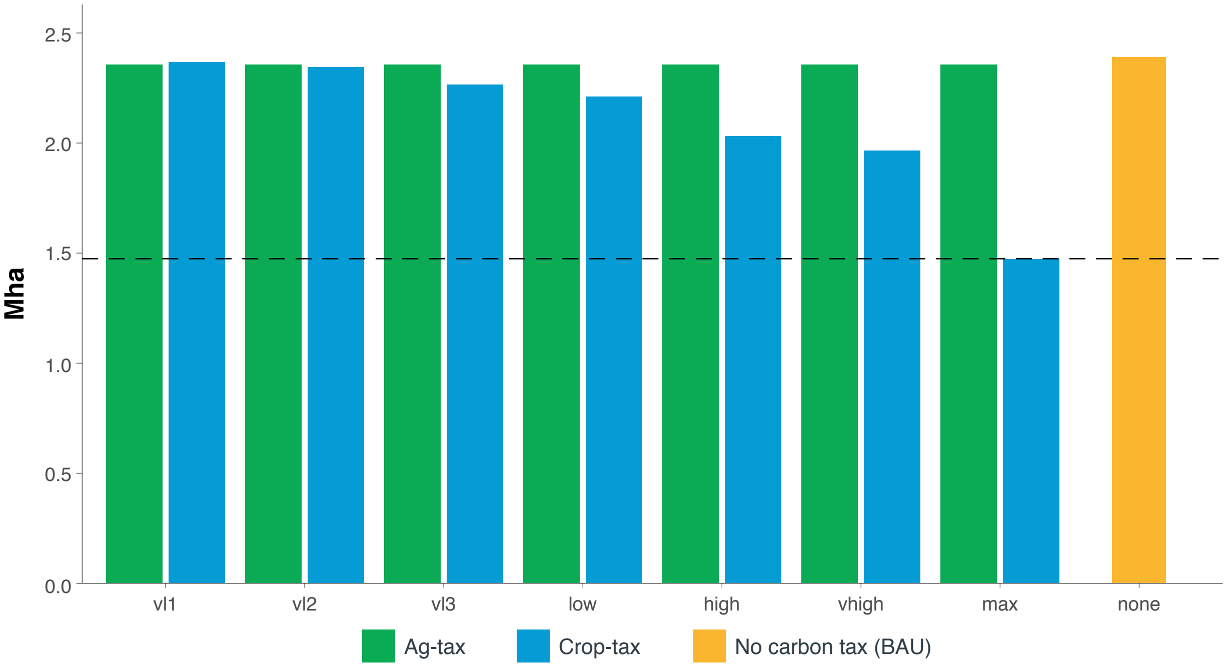
Results shows that a carbon tax, even at low carbon prices, can effectively halt deforestation for agriculture. In the absence of a carbon tax, about 2.2 million ha of forest area would be converted (see Section 5.4). The Crop-tax scenario reduced emissions from land use change by 65 percent by 2050. The Ag-tax scenario reduces emissions from deforestation and other land use change by 99 percent by 2050 compared to BAU, and halts all deforestation and conversion of other natural land even at very low carbon prices (up to US$10/t$CO_2$e by 2050). The difference in the effectiveness is due to the taxation of emissions released from converting other natural land to grassland, which are significant in Zambia.

In both scenarios, cropland area still increases, but less dramatically. The type of emissions taxed and the choice of carbon price have a significant impact on cropland expansion. In the Ag-tax scenario, expanding agricultural area from forest areas is unprofitable due to the carbon taxes, but grassland areas are converted into more profitable cropland. As a result, cropland area is reduced by only 3 percent at any carbon price compared to the no-policy scenario. In the Crop-tax scenario, even low carbon prices impact the profitability of conversion of grassland to cropland, and 8 percent less cropland would be converted by 2050 compared to a no-policy scenario. The expansion of cropland is still profitable in some areas. However, the number of hectares converted in 2050 under carbon price of US$200/t$CO_2$e emission are half of what would be converted at low carbon prices. Thus, at very low prices, there are limited trade-offs on crop production (see Figures 5.18 and 5.19).

Carbon tax policies, if enacted, would affect trade in livestock products and calorie availability. Under the Crop-tax scenario at a very high carbon price in 2050, imports could increase by nearly 30 percent compared to the no-policy scenario. At low carbon prices, maize exports can remain competitive but would shrink; and under high carbon prices millet could shift from being an export commodity to an imported one. Under low carbon prices the impact on trade would be less significant. Under the Ag-tax scenario, where grassland can substitute for cropland, the trade balance of crop commodities would be closer to the no-policy scenario. However, bovine imports would increase, and milk exports shrink. Depending on the mitigation scenario, carbon prices can impact food security. Under the Ag-tax scenario calorie availability falls by about 2 percent through 2050 compared to BAU, and by 1-3 percent under the Crop-tax scenario at very low carbon prices, or by as much as 4 percent if carbon prices are very high.

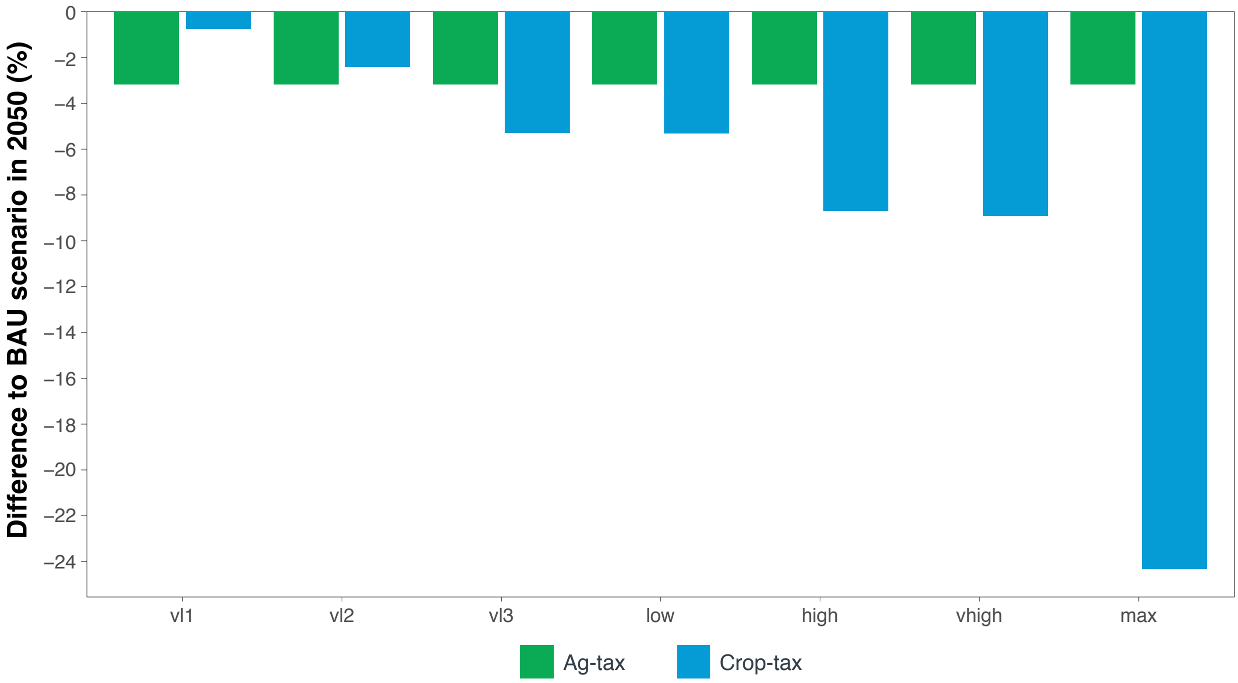
Strict protection of forest and natural land (see the Ag-tax scenario) requires only a very low carbon price to achieve emission reductions and to reduce negative effects on food security indicators. Overall, depending on the goal of the policy (for instance, reducing emissions or protection of forests

Figure 5.18 Available cropland in 2050 under BAU (no carbon tax) and carbon tax policy scenarios with varying prices, in million ha



Sources: IIASA; GLOBIOM model results
Note: Cropland area in 2010 is indicated by the black line. vl1, 2, 3, low, high, vhigh, and max denote different values of carbon prices at: US$5, US$11, US$21; US$40, US$80; US$200; US$1 million per t$CO_2$e emission respectively.

Figure 5.19 Difference in crop production in 2050 under carbon tax scenarios with varying prices as compared to BAU (no carbon tax), in %



Sources: IIASA; GLOBIOM model results
Note: Cropland area in 2010 is indicated by the black line. vl1, 2, 3, low, high, vhigh, and max denote different values of carbon prices at: US$5, US$11, US$21; US$40, US$80; US$200; US$1 million per tCO2e emission respectively.

and natural land) even a very low carbon price applied to emissions from deforestation effectively stops deforestation for crop or livestock production. At a low carbon price that targets only emissions from land use change that results in expanded croplands reduces emissions by 65 percent in the case of BAU, while limiting trade-offs to food security (3 percent less kcals/capita/ per day than with BAU), crop production (5 percent lower than with BAU), and other land use change (27 percent less other natural land compared to 2010). Strict protection of all forests and other natural land requires only a very low carbon price to halt expansion of agricultural area and reduce LUC emissions by 99 percent compared to BAU. Substituting grassland for crop production under a strict land protection scenario would halt all deforestation and other land use change with only limited trade-offs in terms of food security (2 percent less kcals/capita/day) and crop production (2 percent less than with BAU.

5.9 Economic Implications of Scaling-up CSA Adoption

CSA adoption can provide considerable economic benefits: under current CSA adoption rates a 27 percent rate of return on investment is feasible, climbing to 54 percent if the value of reduced GHG emissions is considered. Sections 5.1 to 5.7 showed the potential impact of CSA on key agriculture sector indicators. This section presents the results of an economic assessment of CSA, and its value to Zambian economy. As discussed in Section 2.4, two adoption scenarios were considered: an 8 percent adoption rate, equivalent to approximately 118,000 farmers, equal to the current adoption rate for minimum soil disturbance; and a 50 percent adoption rate, equivalent to approximately 700,000 farmers. The latter reflects the assumption of 50 percent CSA adoption in 2050, as modeled in GLOBIOM for minimum soil disturbance. Both analyses assume an economic cost for rollout of CSA of US$260 per household, resulting in total costs of US$30 million and US$200 million, respectively. Table 5.1 shows that the investment will yield positive returns and is robust against nearly all sensitivity analyses scenarios.

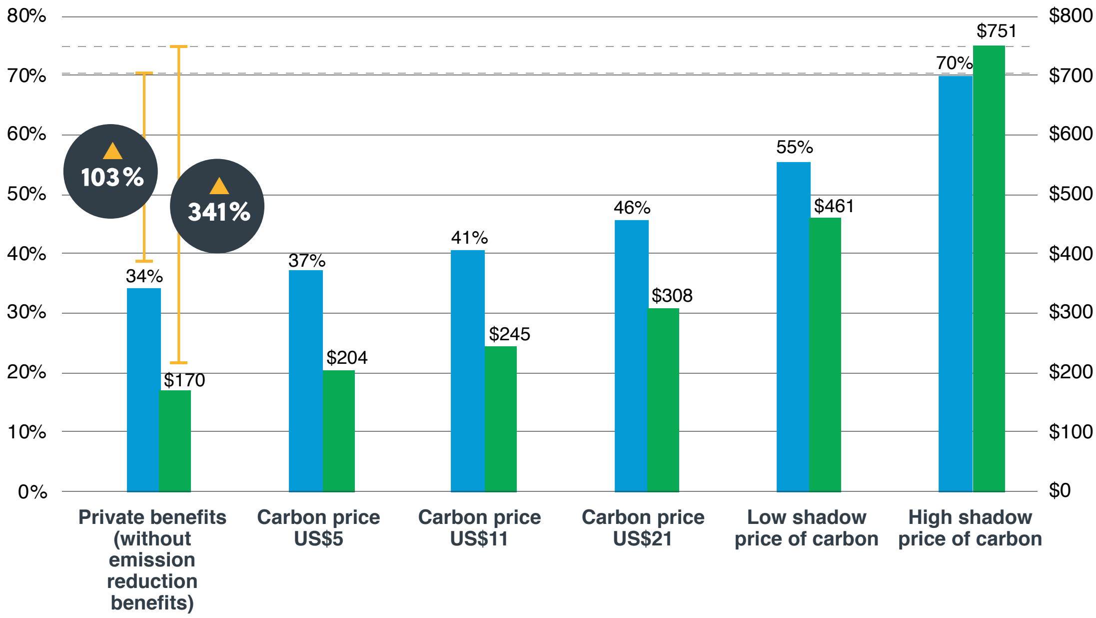
Table 5.1 Economic indicators for two CSA adoption scenarios showing private and public good benefits

	8% adoption						50% adoption					
	Private benefits		Public benefits, low SPC		Public benefits, high SPC		Private benefits		Public benefits, low SPC		Public benefits, high SPC	
EIRR (%)	27%		35%		42%		34%		55%		70%	
NPV (US$)	21 million		35 million		48 million		170 million		460 million		750 million	
Sensitivity analyses: EIRR in %; NPV in million US$												
	EIRR	NPV	EIRR	NPV	EIRR	NPV	EIRR	NPV	EIRR	NPV	EIRR	NPV
Benefits -10%	23%	16	30%	28	37%	40	29%	136	49%	397	63%	653
Benefits -20%	20%	11	26%	22	31%	32	25%	101	43%	334	56%	562
Benefits -50%	9%	-4	13%	2	17%	8.5	12%	-0.6	26%	144	35%	286
Project cost + 10%	24%	18	31%	32	37%	45	30%	153	50%	443	63%	728
Project cost + 20%	21%	15	27%	29	33%	42	26%	135	45%	426	58%	711
Project cost + 50%	15%	6	20%	19	25%	32	19%	84	35%	375	47%	659
Delayed benefits: 1 year	21%	16	26%	28	30%	39	25%	132	38%	391	48%	640
Delayed benefits: 2 years	17%	10.5	21%	21	24%	31	20%	97	31%	326	37%	546
Market price $5	28%	23					37%	204				
Market price $11	29%	25					41%	245				
Market price $21	31%	28					46%	308				

Source: World Bank, own calculation
Note: EIRR stands for Economic Internal Rate of Return; NPV for Net Present Value; SPC stands for shadow price of carbon which means that climate mitigation benefits have been valued at a shadow price of carbon and included as public good benefit in the economic analysis. Sensitivity analyses are conducted for: (i) decreasing private benefits, (ii) increasing investment cost,(iii) delay in realization of benefits, all between 10 and 50%; and for varying carbon market price for GHG emission reduction.

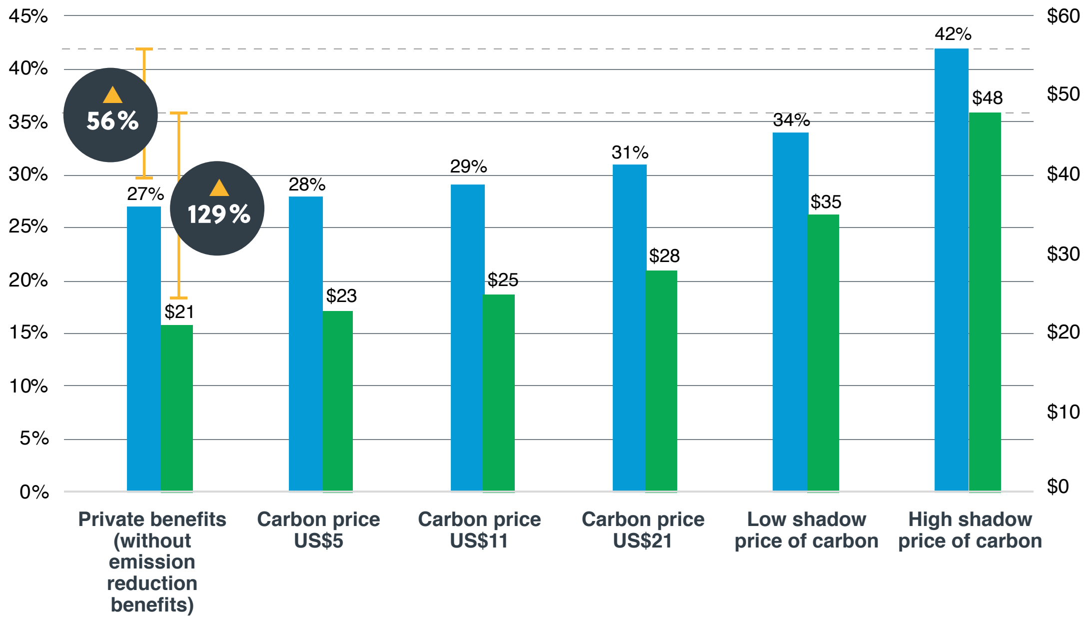
Increasing CSA adoption to 50 percent could generate an economic rate of return of 34 percent if private benefits are considered. Considering the value of emission reduction to society, the net present value of the investment could increase by between 171 percent and 341 percent. Both adoption scenarios achieve a sizable net carbon balance: Over 30 years and under current adoption rates for minimum soil disturbance, an annual net carbon balance of approximately -47,700 tCO_2e emission could be achieved. In a scenario with a 50 percent adoption rate, the annual net carbon balance is approximately -1,137,500 tCO_2e.[13] Valued at a shadow price of carbon (see Section 2.4), the value of emission reduction to society is significant: the net present value in the 8 percent adoption scenario, US$21 million, could increase by between 67 percent and 129 percent; in the 50 percent adoption scenario, it could increase from US$170 million by between 171 percent and 341 percent (see Figure 5.20). Even at potential carbon market prices between US$5, US$11, and US$21/$tCO_2e$ emission (as presented in Section 5.8), the NPV could increase by between 10 and 14 percent in the current adoption scenario; and between 20 percent and 81 percent in the 49 percent adoption scenario. While the absolute value of emission reduction in tCO_2e emissions is small compared to Zambia's ambitious NDC goals, the potential economic value to society is large.

Figure 5.20 Effect of climate mitigation benefits stemming from the scaling-up of CSA to 50% of smallholders on economic indicators (EIRR in %; NPV in US$ million)



Source: World Bank, own elebatoration

Figure 5.21 Effect of climate mitigation benefits stemming from adoption of CSA by 8% of smallholders on economic indicators (EIRR in %; NPV in US$ million)



Source: World Bank, own elebatoration

Section

6

Prioritizing CSA Practices

Crop diversification, commercial horticulture, agroforestry, and reduced post-harvest losses, produce some of the strongest results with relatively few trade-offs between positive outcomes on the household and sector level. Sections 4 and 5 discuss CSA impacts on household welfare and on sectoral performance, respectively. Section 7.1 describes CSA against the backdrop of Zambia's enabling environment, and Section 7.3 elaborates which practices have received donor-funds in the past year. The aggregated results of both reviews are presented in Table 6.1 in the column "Feasibility". Based on these findings, Table 6.1 ranks every CSA practice to enable decision-makers to prioritize investments in the sector. Reading the table from left to right suggests that CSA practices such as crop diversification, commercial horticulture, agroforestry and reducing post-harvest losses are more effective than others at delivering on key indicators. Reading the table from top to bottom suggests that some evaluation criteria, for example, food security criterion receives a boost from most CSA practices, while the effect of CSA on GHG emission reduction—excluding the potential for soil carbon sequestration due to modeling constraints—seems varied. What is needed is an enabling environment and investment strategies that will enable and accelerate adoption of these practices and maximize their impact.

Table 6.1 Impacts of CSA practices on key decision variables

	Past household-level impact			Projected sector-level impact			Rural Develop-ment	Feasibility	
	Income	**Reduce income variability**	**Food security**	**Crop yield**	**GHG mitigation**	**Food availability**	**Job creation & market linkages**	**Available funds**	**Enabling environment**
Minimum soil disturbance	🟡 **Wet conditions (–)** Long run positive; short run negative; strong geographic variation	🔴	🟡 Crop yields increase, strong spatial variation	🟡 **Climate change (–)** Strong increase under BAU; decrease under climate change	🟢 **Climate change (++)** Enhances soil carbon sequestration	🟢 **Climate change (++)** Contingent on adoption taking place in favorable areas	🟢 Requires establishment of input markets (implements, inputs, mech-anization)	🟢	🔴
Residue retention	🟢 **Wet conditions (–)**	🟢	🟢 **Dry conditions (+)**	🔴 **Climate change (–)** Slight increase under BAU; negative under climate change	🟡 **Climate change (–)** Increased fertilizer emissions; but soil carbon sequestration occurs	🔴 **Climate change (–)**	🟡 No notable impact	🟢	🔴
Crop rotation/ intercropping	🟢 **Wet conditions (–)** Long run positive; short run neutral	🟡 Strong geographic variation	🟡 **Dry conditions (+)** Strong geographic variation	n/a	n/a	n/a	🟢 Investment in legume value chain development and processing; access to new markets (traders, processors) creating job opportunities	🟢	🔴
Crop diversification (largely legumes)	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟢	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟢 **Climate change (–)** Increases for most crops, though less under climate change	🟡 **Climate change** Increased fertilizer emissions; but soil carbon sequestration occurs	n/a		🟡	🟡 Ongoing reforms expected to lower barriers
Commercial horticulture	🟢 **Dry conditions (+)**	🟢	🟢	n/a	n/a	n/a	🟢 Access to new markets, processing and value addition	🟡	🔴
Agroforestry	🟡 No effect in the short term	🟢	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟢 **Climate change (–)** Increase is less under climate change	🟢 **Climate change (–)** High levels of soil carbon sequestration and biomass growth	🟢 **Climate change (++)**	🟡 Low potential of value chain development (maybe nursery)	🟡	🔴
Livestock diversification	🟡 **Wet conditions (–)** No significant impact; geographical variation	🟢 **Dry conditions (+)**	🟢 **Dry conditions (+)**	n/a	🔴 Increase in livestock herds increases methane emissions	n/a	🟢 Opportunities for veterinary services, trading, processing	🟡	🟡 Ongoing policy reforms expected to lower barriers
Delayed planting	🔴 **Dry conditions (–)** **Wet conditions (–)**	🔴	🔴	n/a	n/a	n/a	🟡 Development of input markets and advisory services	🟡	🔴
Drought- and heat-tolerant seeds	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟢 **Dry conditions (+)** **Wet conditions (+)**	🟡 No notable increase under BAU; positive under climate change	🟡 No change under BAU; climate change could equally increase/ decrease the effect on mitigation	🟡 No change under BAU, positive effect under climate change	🟡 Development of input markets can create jobs	🟡	🟡 Moderate constraint
Reducing post-harvest loss	n/a	n/a	n/a	🟢	🟢	🟢	🟢	n/a	🔴

Source: World Bank, own elaboration

🟢 Strong positive effect 🟡 Low-medium positive effect 🔴 Negative effect

Note: (i) Colors (green, yellow, red) indicate the impact of CSA practices on key indicators where green indicates a positive effect, yellow a low-to-medium positive effect; and red a negative effect; (ii) Dry conditions/Wet conditions +/- indicates whether increased or decreased rain have a positive or negative effect on CSA's impact on the key indicator; (iii) Climate change ++/+/- corresponds to the error bars in GLOBIOM figures and indicates the magnitude and directionality of the range of effects that a CSA practice can have on indicators. It indicates whether the effect is strongly positive, or rather positive or negative under climate change projections. n/a indicates that due to data and methods constraints a quantitative analysis couldn't be conducted. (a) Information on Enabling Environment and Available Funds, can be found in Section 7.

Section

7

Enabling Environment and Mechanisms to Promote CSA

7.1. Incentivizing CSA Adoption by Improving the Institutional Enabling Environment in Zambia

Historically, adoption rates of CSA practices have been low and there has been uncertainty over whether the institutional and policy enabling environment have hindered adoption. As discussed in previous sections of this report, CSA practices, if tailored to specific biophysical conditions, can enhance household net incremental benefits, resilience, and welfare indicators and support both agriculture sector goals and aggregated economic benefits including public good benefits. Several barriers to adoption have been identified related to high upfront and labor costs. Section 7.1 summarizes key features of the institutional enabling environment which could enhance or hamper the adoption of CSA in Zambia. Section 7.2 introduced eight innovative and proven investment strategies which could help overcome these constraints and support a broad adoption of CSA.

Security of land tenure is a key driver of on-farm investment. In rural Zambia, customary tenure is most common, and this likely impedes productive investment. Customary tenure is governed by traditional norms under which land is administered by a headman such as a chief. Land under customary tenure cannot be legally transferred, and traditional leaders have a large degree of autonomy in making decisions about the use of land, which causes uncertainty and insecurity regarding property rights—usage rights, management rights, and transfer rights. Customary tenure also complicates long-term investments which are critical for many CSA practices, such as agroforestry and the fencing of crop residues to avoid livestock intrusion. By contrast, commercial farmland is regulated by statutory tenure, which in Zambia is administered through the government's Ministry of Land and Natural Resources and also applies to urban areas and district municipalities. Evidence shows that land tenure status is a significant factor in whether or not smallholders adopt irrigation systems (Ngoma et al. 2017). There is also evidence that a shift from usufruct rights to full ownership increases incentives for soil conservation and productive investments such as tree planting (Deininger and Feder 2009). Improving tenure rights, transparency, and security would also substantially improve women's economic prospects (Namonje-Kapembwa and Machina 2018).

Capacity building and agricultural extension services are key for agricultural development and adoption of improved technologies. However in Zambia, public extension services are severely underfunded. Subsistence farmers are conservative adopters of technology, and need capacity building, extension and advisory services to make CSA adoption more effective and minimizes risks. While the Zambian government has acknowledged in several policy documents[14] the need for a strong extension system, there are significant gaps in: institutional capacity; technical and training capacity; planning; reporting and feedback; initiatives pertaining to non-functional value chains; extension officer-to-farmer ratios; and coordination and communication. For examples, agriculture made up 9 percent of the government's budget in 2015, a mere 2 percent of that, or ZMK89 million, was channeled toward agricultural research and extension services, as compared to the more than 50 percent budget allocated to the FISP and FRA programs (Kuteya et al. 2016). As a result, there are very few extension and advisory services that cater to the specific needs of women smallholders. In addition, agricultural extension services emphasize maize, a staple, rather than a more diverse set of nutrient-rich alternatives that are traditionally produced by women.

Information and communications technologies (ICTs) can be valuable in providing agricultural advisory services to farmers although coverage and service delivery will need to be improved. Empirical evidence shows the tangible and positive impact of ICTs on agriculture. Increased mobile phone coverage in Uganda has helped farmers to better coordinate the storage and sale of perishable commodities and to achieve higher prices (Muto and Yamano 2009). ICTs also support the adoption of agricultural technologies, by allowing social learning and private information sharing (Goyal and González-Velosa 2012). ICTs also potentially increase opportunities for women, who face barriers in accessing inputs and information, and might also improve youth engagement in modern agricultural systems. In Zambia mobile phone usage has grown sharply (from <10 percent of the population in 2005 to 80 percent in 2018); by contrast internet penetration is around 47 percent, according to the ZICTA Statistics Portal. However, overall access to reliable ICT services is limited and often nonexistent in rural areas. Even in areas with coverage, the poor service delivery hinders effective use.

Access to financial services and credit constrains adoption of improved technologies and enhancement of business opportunities in the agriculture sector. Low population density, low income, and poor financial literacy contribute to an environment in which it is too expensive to offer loans to smallholders. Only 15 percent of Zambia's 1.5 million farmers have taken out loans, two thirds of which can be attributed to outgrower schemes, specifically for farmers with landholdings between 0.5 ha and 20 ha. Commercial finance is virtually nonexistent, except for large and medium size farmers. Households with less than 0.5 hectares of land resort to informal loans (Chapoto and Zulu-Mbata 2016). There are several feasible approaches to enhance access to finance: financial guarantee mechanisms that would allow financial institutions to provide services to emergent or commercial farmers, or alternatively agro-suppliers to provide smallholder farmers with seeds and fertilizer on credit that would be paid back once crops were sold. Also, warehouse receipt systems might offer farmers collateral that would enable them to get credit from microfinance institutions; and matching donor grants or credit lines extended to smallholders or cooperatives of smallholders could also be an option. All of these approaches dovetail with the provision of specific agricultural and financial advisory and extension services (World Bank 2018b; Chisanga and Chapoto 2018).

Inadequate production and market infrastructure impedes development of and access to domestic and regional agricultural markets, which reduces income opportunities and incentives to invest in new practices or diversify production. Irrigation infrastructure in Zambia is particularly poor, despite enormous potential, and the importance of irrigation in crop diversification. Empirical evidence confirms that households situated in wetlands are more likely to diversify crop and agriculture income than those situated in dry areas (World Bank 2018d). Minimizing distances to paved roads reduces transportation costs for both inputs and outputs, connecting farmers to markets and providing incentives to adopt improved practices or diversify production. Shorter distances to roads have been shown to have a significant positive effect on the establishment of small and new agro-processing firms (Norman et al. forthcoming).

Improved access to markets is considered a driving factor for changes in production patterns. Farmers tend to specialize in crop production with high market demand when they live closer to urban centers (World Bank 2018d). There are examples of partnerships between rural communities and agribusinesses, where agribusinesses provide a reliable market for farmers' produce, provided farmers are using improved agricultural practices (Lewis et al. 2011). In addition to hard market infrastructure, improved business skills, timely information about market prices, or the possibility to coordinate and aggregate produce, for instance through a farmer association or producer group, can enhance farmers' market access.

Distortionary public policies and subsidies encourage the adoption of mono-cropping under conventional management practices. The Zambian government maintains price and input support programs that consumed an average of 79 percent of the national agriculture budget between 2008 and 2016 (World Bank 2017a). Recent studies show that FRA's maize purchases reduce the likelihood of farmers diversifying crop production and crop income (World Bank 2018d; Mofya-Mukuka and Shipekesa 2013). Traditional input subsidy programs impede the development of private input markets and incentivize production of one crop, rather than enabling diversification and adoption of improved practices. In the 2015/16 season, the Zambian government piloted an e-voucher system that increased transparency (in terms of the beneficiaries who receive subsidies), increased competition among agro-dealers which boosted prices and diversification, and encouraged farmers to redeem vouchers for diverse crop and livestock products. An evaluation of the pilot has shown that farmers still tend to redeem inputs vouchers for maize-related products, possibly due to lack of capacity or poor timing in the provision of subsidies, that is subsidies are provided too late to enable another crop than maize to be planted. FSIP should support crop diversification, be paired with capacity building efforts to improve adoption of new practices and technologies, and roll out training for agro-dealers (Kuteya et al. 2018). The savings achieved from these reforms could then be allocated to productive investment such as irrigation, agriculture research and extension services, or building rural infrastructure (World Bank 2017a; World Bank 2018a).

Table 7.1 shows that three conditions appear to be most constraining for the adoption of CSA: the lack of capacity building, lack of access to finance, and access to markets. These constraints should be addressed in going forward, which will facilitate the promotion of priority CSA practices as identified in Section 6. For agroforestry, crop diversification, and commercial horticulture, capacity building and receiving appropriate advisory services is a constraining factor for adoption. Access to finance in order to obtain new varieties and farming equipment including on-farm storage solutions, as well as access to input and output markets which is a key incentive to improve and diversify farming practices, are constraining the adoption of prioritized CSA practices.

Table 7.1 Evaluation of dimensions of a conducive enabling environment for the adoption of CSA

	Land tenure systems	Capacity building	Access to finance	Access to rural infrastructure	Access to markets	Distortionary public policies
Conservation agriculture *(minimum soil disturbance, residue retention, rotation)* **Agroforestry**	🔴 Lack of secure tenure is a disincentive to adopt practices with deferred benefits	🔴 Deferred benefits pose a risk to farmers but this can be mitigated by adequate capacity building	🔴 Upfront costs (e.g., inputs, labor, mechanization) are found to impede adoption	🟢	🔴 Opportunities to generate income reduce risk of adopting new practices	🟡 Fertilizer subsidies may decrease economic rational for adoption; subsidy schemes could be paired with advisory services to enhance adoption.
Commercial horticulture	🟡 Horticulture has short cultivation cycle, and can be cultivated on small plots; insecure land titles could hinder investment in irrigation systems.	🔴 Diversifying into new crops requires access to advisory services	🔴 Access to finance critical as new inputs, infrastructure and transport are needed to set up operations	🔴 Irrigation, roads, and access to markets crucial for stable production and links to agri-businesses		🟡 Can lead to lower competition among input suppliers and traders as well as higher input costs
Livestock diversification	🟢 Mobile asset; grazing often occurs on communal land	🔴 Diversifying into new species requires access to advisory services incl. animal health	🟡 To start operation, access to finance critical; livestock serves as "savings bank"	🟢	🟡 Access to new species, and health services is a challenge	🟡 Current focus on maize impedes the production of crops to develop livestock feed industry
Timing of planting	No specific impact	🔴 Lack of advisory services affects planting decisions	🔴 Lack of inputs negatively affects timing of planting	🟡 Access to infrastructure facilitates delivery of inputs and reduces involuntary planting delays	🔴 Lack of input markets often causes planting delays	🔴 Late delivery of subsidies was found to affect timing of planting
Drought- and heat-tolerant seeds	🟡 Benefits accrue shortly after planting	🟡 No specific capacities compared to conventional practices	🔴 Improved seed usually costly, access needed to start operation	🟢	🟡 No specific difference from conventional practices, except supply of seeds.	🟢 FISP has facilitated access to improved maize seeds
Crop diversification	🟡 Research shows small land sizes disincentivize diversification	🔴 Access to advisory services a crucial driver of diversification	🔴 Access to finance critical new inputs needed to set up operation	🔴 Access to markets and irrigation supports diversification		🟡 Disincentivizes diversification; but ongoing reforms of FISP could reduce barriers
Reducing post-harvest loss	🟢	🟡 Access to advisory services can help reduce post-harvest losses on farm	🔴 Access to finance critical to get access to adequate technologies	🔴 Access to rural infrastructure includes storage facilities which are critical	🔴 Access to markets provides incentives to reduce post-harvest loss	🔴 Disincentivizes private sector involvement in storage and warehouse facilities

Source: World Bank, own elaboration

🟢 Low barriers to adoption 🟡 Medium barriers to adoption 🔴 High barriers to adoption

7.2 Summary of Innovative Delivery Mechanisms to Support CSA Adoption

Innovative approaches are required to promote CSA adoption in Zambia and can help to overcome barriers in the enabling environment. Even though long-term household benefits incentivize CSA adoption at the farmer level, adoption remains low, often because information, skills and support to cover upfront costs are missing, inadequate access to finance, and lack of input and output markets (see Table 7.1). Several mechanisms have been evaluated that can overcome these barriers. This section presents eight mechanisms, which can be treated as investment options or project interventions to rollout the adoption of CSA. A more detailed description is presented in and Appendix G. Table 7.2 also indicates which of the three key enabling constraints, that is, inadequate access to finance, access to markets and capacity building, they can address.

Table 7.2 Delivery mechanisms and their potential to address enabling environment constraints

Delivery mechanisms	The delivery mechanisms have the potential to enhance:		
	Access to finance	Capacity building and advisory services	Access to markets
Business partnerships with rural communities—leveraging carbon finance	✓ Contracts can serve as collateral; Agribusiness could facilitate access to carbon finance	✓ Farmers receive training on relevant commodities and practices	✓
Outgrower scheme—commercializing horticulture production	✓ Contracts can serve as collateral; agribusiness may provide loans to participating farmers	✓ Farmers expected to receive training on relevant commodities and practices	✓
Participatory integrated landscape management approach—achieving multiple objectives	✓ Mitigation benefits from landscape approach could enhance eligibility to participate in a carbon finance project	✓ Participatory element facilitates knowledge exchange	No specific impact
Farmer field school—community-based learning and technology adoption	No specific impact	✓	✓ "farming-as-a-business" trainings and engaging in farmer associations facilitate market access
Pluralistic participatory extension approach—supporting linkages between research and dissemination	No specific impact	✓	✓ Service providers connect farmers to markets; "farming-as-a-business" trainings provided
Weather index insurance —combining risk transfer with risk management	✓ Can be combined with access to savings banks, revolving funds and financial literacy training	✓ With mandatory CSA adoption policyholders should receive trainings	No specific impact
Cash transfers—Alignment with the Harvesting Cycle to Promote CSA	✓ Payments at correct time of season can cover upfront cost for agricultural investment	✓ Could be paired with demonstrations and capacity building	No specific impact
Gender sensitive supply chains	✓ Reducing barriers for women to access finance	✓ Reducing barriers for women to receive adequate training	✓ Reducing barriers for women to enter markets

Table 7.3 Comparing innovative delivery mechanisms for scaling up CSA

Investment cost over 6 years ($ million)	Benefit-cost ratio[a]	NPV[b] ($ million)	EIRR (%)	Investment areas and public sector activities
Weather index insurance (WII)—combining risk transfer and risk mitigation[c]				
US$15.7	1.32	US$4.14	18.8%	(i) Capacity building and training of farmers, insurers and regulators, including development of guidelines and training modules, sensitization for formation of local saving groups (ii) Provide technical and operational support for agricultural insurance scheme (e.g., feasibility study, product and scheme design, involvement of private partners); product delivery and operation; marketing, monitoring and results dissemination (iii) Ensure data availability, functionality, and integrity of weather station (iv) Reduce legal and regulatory risks to policyholders and insurers (v) Appoint an independent agency to verify, on behalf of insured parties, contract and payout accuracy (vi) Improve and maintain operationalization of the electronic voucher system
US$20.14 (including subsidized premium of US$10-30)	1.03	US$0.5	11%	
Business partnerships with rural communities—leveraging carbon finance				
US$25.1	1.6	US$13.3	31%	(i) Ensure that the project is aligned with regional and community development plans (ii) Provide capacity building and training for farmers to adopt CSA, post-harvest management, and farming as a business (collective marketing, business, marketing, quality control) (iii) Promote business linkages with producer groups, agro-dealers and storage facilities; conduct farmer trade fairs; conduct market research of target crops (iii) Support access to credit by enhancing capacity of commercial banks and strengthening the policy and regulatory environment, e.g., access to inputs, revolving funds, purchasing logistics, equipment and packaging materials (v) Factor private sector needs into investment in public goods and services
Pluralistic participatory extension approach—supporting linkages between research and dissemination				
US$51.2	0.75	-US$10	4.4%	(i) Support agricultural research and development facilities and specific research through public research centers to develop and test improved practices (ii) Coordination of pluralistic extension services (iii) Capacity building for public extension officers and lead farmers (iv) Setting up the FFS for demonstration purposes (v) Develop sectoral or local policy that supports private sector service provision (vi) Develop integrated planning skills for local governments (vii) Support development and strengthening of farmer organizations
Farmer field school—community-based learning and technology adoption				
US$22.54	1.7	US$12.7	38.58%	(i) Support sensitization of farmers to adopt new learning approaches (ii) Support the identification of farmers and formation of learning groups and strengthen farmer groups involved in the FFS (iii) Provision of initial production inputs, clean materials for establishing demonstration plots and seed multiplication schemes; and CSA learning material (iv) Support suitability and prioritization studies for crops and CSA practices (v) Conduct field days and knowledge exchange between different groups

Source: World Bank, own elaboration
Note: (a) Benefit-cost ratio was calculated by dividing discounted benefits over 30 years by discounted cost (investment cost and maintenance cost) over 30 years. A discount rate of 10% was used. A ratio above one indicates profitable investment. (b) NPV was calculated at a discount rate of 10 percent and for approximately 118,000 beneficiaries. (c) The assessment of insurance benefits is not straightforward. For this analysis we rely on Varadan and Kumar (2012) who found that crop insurance can absorb production risk and increased input use. Insured farmers spent more on inputs and realized higher returns from farming (+125 percent) than their non-insured counterparts.

Table 7.3 Continued

Investment cost over 6 years ($ million)	Benefit-cost ratio[a]	NPV[b] ($ million)	EIRR (%)	Investment areas and public sector activities
Outgrower scheme—commercializing horticulture production				
US$25.13	1.39	US$7.9	21.1%	(i) Support the development of irrigation infrastructure and governance structures (ii) Support for contract design and enforcement (iii) Support smallholder capacity and coordination (iv) Promote private sector adherence to principles of responsible investment (v) Support effective public-private dialogue to build (regional) markets (vi) Ensure compliance with social and environmental standards (vii) Improve land tenure security and access to land (viii) Invest in public goods and services considering private sector need (ix) Enhance public inspections and quality assurance
Participatory integrated landscape management approach—achieving multiple objectives				
US$28.1	2.32	US$30.1	36.4%	(i) Ensure compatibility with community, landscape and public sector goals (ii) Community planning: support risk and vulnerability assessments; support community organization; formation and strengthening of groups; support land management/watershed planning with relevant tools (e.g., GIS, ICTs) (v) Capacity building: train communities or link them with service providers to address vulnerabilities in landscape (vi) Infrastructure, logistics materials: provide materials for land restoration, production inputs, watershed management, materials for forest management (iii) Review legal and regulatory set-up and whether there is need for reform (iv) Initiate dialogue and facilitate process
US$28	1.41	US$9.6	22.4%	**Livestock:** (i) Develop animal husbandry productivity assessments and implementation plans (ii) Support procurement and distribution of improved planting material (iii) Support forage demonstration and promotion activities (iv) Support animal health services and vaccination

Table 7.3 provides suggested steps for the public sector to follow to help crowd-in private sector financing to support adoption of CSA. Currently, public resources are either scarce or are not being used effectively to support achievement of sector goals. The World Bank is committed to the Maximizing Finance for Development (MFD) framework, which aims to support public sector activities in a manner that crowds in and maximizes private sector investment. The MFD framework promotes a range of potential actions to crowd-in the private sector: promote responsible investment; increase the private sector space by removing restrictions; improve the policy and regulatory environment for private sector investment; reduce transaction costs and risks; and use public resources to invest in public or quasi-public goods and services (World Bank 2018c). Table 7.3. provides for each investment opportunity a range of activities that can support private sector involvement to fund the respective mechanisms. See Appendix G for a further discussion of each delivery mechanism.

Weather Index Insurance—Combining Risk Transfer with Mitigation

Weather index insurance (WII) is a risk transfer mechanism to enhance household's resilience against climate change. In Zambia, the World Food Program (WFP) pairs WII with risk mitigation strategies and mandatory CSA adoption. WII compensates policyholders based on a weather index (for example, rainfall) and estimates losses in a particular location and period of time. In their Rural Resilience Initiative (R4) program, WFP paired WII with the roll out of CSA. The R4 has four components: improved resource management and CSA (risk mitigation); insurance (risk transfer); livelihood diversification; and microcredit (prudent risk taking), and savings (risk reserves). The R4 provides a high level of services to farmers and has so far reach approximately 4,000 households (WFP and OXFAM 2017).

Business Partnerships with Rural Communities—Leveraging Carbon Finance

Agribusinesses play a pivotal role in enhancing the profitability of agriculture-related climate change mitigation by: incentivizing farmers to adopt CSA practices; providing market opportunities for compliant farmers; and extending access to carbon finance. Under this arrangement, an agribusiness develops processed products, which are certified as environmentally and socially sustainable. The agribusiness provides farmers with premium prices if they adopt CSA and natural resources management practices that will advance climate mitigation. If the agribusiness can demonstrate emissions have been reduced, the resulting emission reduction credits can be sold to a carbon fund. In Zambia, the company Community Markets for Conservation (COMACO) is a well-known example of this business-model. Following the first successful verification of carbon credits in October 2017, BioCarbon Fund[15] paid US$814,406 to participating communities and COMACO. The model is attractive for urban consumers who can contribute to climate mitigation by buying certified labelled products. However, accessing carbon funds is often hampered by high transaction costs. COMACO receives donor funding to finance supervision, monitoring, and implementation of its community activities (World Bank 2018c).

Outgrower Schemes—Commercializing Horticulture Production

Outgrower schemes are a form of contract farming in which smallholder farmers and agribusinesses or processing plants engage in a binding agreement. Through this coordinated commercial relationship, the company typically provides support to the farmers with production planning, input supply, and adoption of new technologies including CSA practices, extension advice, and transport. Farmers benefit by gaining access to markets and financial services, reduced price fluctuations and by receiving support in achieving quality standards and technology, skills and knowledge transfers, and opportunities for seasonal employment. There is a risk, however, of dependency, power asymmetry, limited transparency and even disputes over prices and contract conditions. Outgrower schemes are feasible with all types of crop production, but are most often used to source horticulture products and combined with access to small-scale irrigation.

Pluralistic Participatory Extension Approach—Supporting Linkages Between Research and Dissemination

The pluralistic participatory extension (PPE) approach harnesses different sources of advisory services to disseminate innovative technologies. Extension and agricultural advisory services are key for spreading the adoption of CSA and achieving development goals. The PPE approach recognizes the diversity of farmers and farming systems, and is characterized by the coexistence of multiple public and private sector approaches, providers, funding streams, service types, and sources of information and experiences. Service providers can include membership-based farmer organizations, private and commercial enterprises, and non-governmental organizations (NGOs). The PPE approach works well with agricultural research services, and supports the development and testing of climate-resilient solutions for smallholder farmers (Heemskerk and Davis 2012).

Farmer Field Schools—Strengthening Community-Based Learning and Technology Adoption

Farmer field schools (FFS) provide education and extension services often with a focus on CSA practices. FFS have emerged as a complementary and reinforcing approach to traditional agricultural advisory services and provide season-long programs for farmers to regularly meet, learn, and experiment with particular topics. They leverage experiential learning and a community-learning approach (Davis et al. 2012). The FFS are based on a combination of demonstration, explanation, and evaluation of new crop technologies, and field days and exchange visits to facilitate learning and sharing of innovation (Anandajayasekeram 2007). FFS interventions are often decentralized and implemented by local authorities, NGOs, community organizations, and even the private sector.

Integrated Participatory Landscape Management Approaches—Achieving Multiple Goals

The landscape management approach entails planning interventions at a larger geographic level, such as a watershed, catchment or communal area, and is planned through a participatory land management method. The landscape approach incorporates a set of tools, concepts, methods, and approaches deployed in a specific landscape to achieve several economic, social and environmental objectives and provide vital ecosystem services under the management of the people using the land and producing those services (Sayer et al. 2013). The theory is that CSA strategies—but also forestry management practices, improved livestock management, and rangeland and water management—should not be analyzed and implemented in isolation, but within a framework of broad landscape management. Despite being a multi-stakeholder process, landscape management approaches typically exclude the private sector. While there are opportunities for private sector involvement, for example, through sustainable investments and market and job opportunities, there are concerns about power relations or the derailment of the approach's objectives.

Cash Transfers—Alignment with the Harvesting Cycle to Promote CSA

Cash transfers seek to promote agricultural production while combating poverty and hunger and strengthening future generations of human capital for (Boone et al. 2013). Access to capital, particularly for rural populations in extreme poverty, is largely nonexistent. Cash transfers provide infusions of capital as an incentive to invest in agriculture, and can be rolled out in combination with CSA practices. In tandem cash transfers and CSA address the bottleneck caused by high upfront costs of many CSA practices and also enhance the resilience of the rural poor. Evidence suggests that cash transfers can also increase agricultural production and self-sufficiency. In this way, cash transfers are believed to help households surmount the initial barrier toward higher socioeconomic mobility (Boone et al. 2013; Tesliuc 2013).

Gender-Sensitive Supply Chains—Facilitating Access to Assets and Services for Women

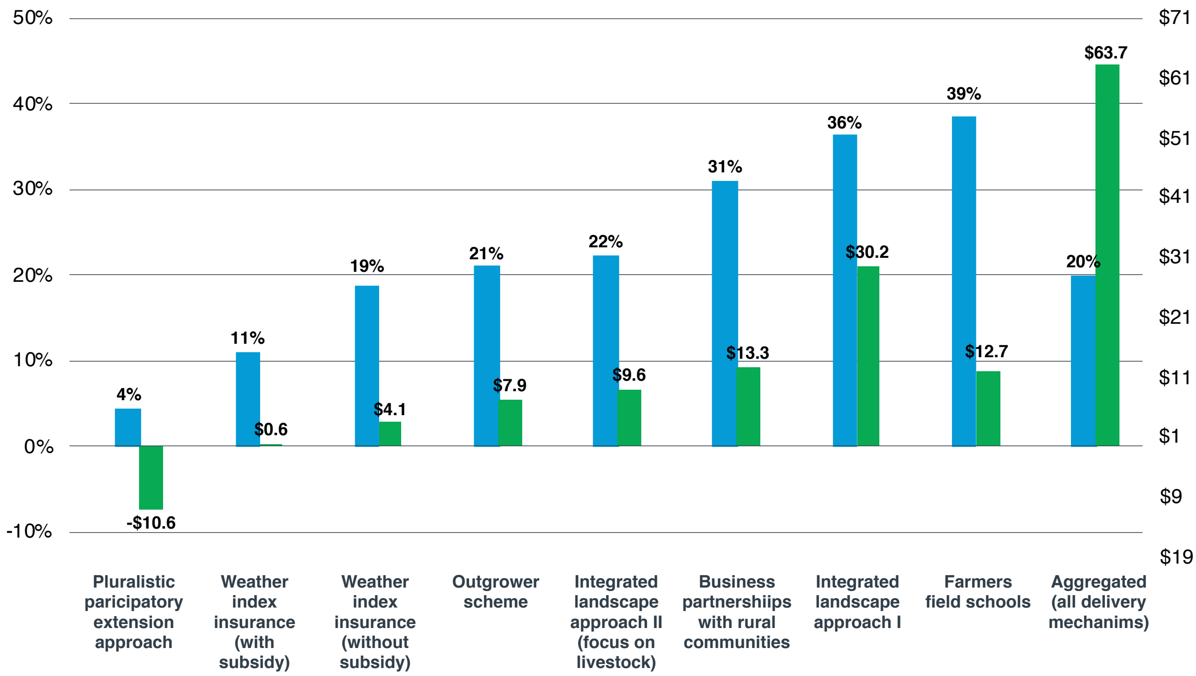
The development of gender-sensitive supply chains offers women access to the same markets and resources as men. A number of socioeconomic barriers prevent women from enjoying equal access to land, markets, educational resources, and networks. This inequality is exacerbated by the additional pressures women face in managing a workload that includes earning a livelihood, caring for children, and performing domestic duties. Case studies in Ghana and Uganda confirm the negative impacts of gender work imbalances on farming, particularly in the context of cash crop production. In Ghana, women's access to liquid capital for purchasing inputs was limited, which led many women to use sub-optimal production technologies (Hill and Vigneri 2014). These constraints have to be considered when implementing CSA programs.

7.3 Investment Requirements to Scale-up CSA

Cost-benefit analyses are conducted for six investment options and show that investment in nearly all mechanisms exceeds the opportunity cost of capital, even without factoring in environmental benefits. The analysis assumes that each mechanism will be rolled out to 8 percent of smallholder households, thus approximately 118,000. Table 7.3 provides results for six mechanisms, where weather index insurance and integrated landscape management approach are available in two variations, and shows that nearly all of them have a favorable economic rate of return on investment, where farmer field schools have the highest rate of return with 39 percent, followed by integrated landscape management approach, 36 percent, and business partnerships with rural communities, 31 percent. The pluralistic participatory extension approach has the lowest economic internal rate of return (EIRR) at 4.4 percent. This approach aims to strengthen agricultural research and development, and benefits may not be immediately evident. Weather index insurance entails the lowest average investment cost per household, and participatory pluralistic extension services the investment cost over 6 years of project duration with US$51 million. The NPV of investment is positive for all enterprises except pluralistic participatory extension approach.

Business partnerships with communities, farmer field schools, and the participatory, integrated landscape management approach seem most promising mechanisms. Considering economic indicators and effectiveness to address constraints to CSA adoption, these three investment options seem most promising. Business partnership with communities could facilitate access to markets, finance and capacity building, and demonstrate an economic internal rate of return on investment of 31 percent. Farmer field schools and integrated landscape management approach address two constraints but have relatively high rates of return of 39 percent and 36 percent. Business partnerships with communities, which aim at participating in a climate finance project, can be combined with integrated landscape management approaches.

Figure 7.1 Economic internal rate of return and net present value of 7 delivery mechanisms, individual and aggregated



Source: World Bank, own elaboration
Note: For each delivery mechanism economic indicators are calculated for approximatly 118,000 beneficiaries; aggregated this results in approximatly 826,000 beneficiaries

Box 7.1 Public sector expenditure on agriculture in 2017

CSA-related expenditures in 2017 have been assessed based on secondary data about public (IAPRI 2018) and donor (von der Decken 2017) expenditures, in combination with primary data collected from 25 different CSA donors and project implementers.

Government expenditure: In 2017 the GoZ allocated approximately US$540 million to the Ministry of Agriculture and US$64 million to the Ministry of Fisheries and Livestock (IAPRI 2018), which together accounted for 9.4 percent of the total national budget. Seventy percent was allocated to FISP and FRA. The remainder, about 20 percent, or US$108 million, was available for alternative public investments, including in extension support, research, and development.

Donor support for the agriculture sector in Zambia is substantial: As of 2017, donor partners have allocated more than US$1 billion to support agriculture sector projects.

Donor disbursement by category: Donor disbursement was categorized according to the categories in Zambia National Agriculture Investment Plan, in which CSA did not represent a separate category. The largest share of donor allocations went to improving crop productivity (28 percent), followed by market access and service delivery (17 percent). Crop productivity improvements relate directly to the CSA goals. Knowledge support systems and research, food and nutrition security and risk management, and sustainable natural resource management are evenly split in terms of budget allocation at 13 percent each. Livestock and aquaculture productivity improvements receive a much lower budget allocation compared to allocations to crops, totaling 14 percent together. As of 2017, major donors in Zambia disbursed a total of nearly US$173 million to 80 agriculture and natural resource projects (von der Decken 2018).

Funding for CSA practices: Based on interviews with 25 major donors and project implementers, including public sector entities, an estimated US$118 million was spent in 2017 on 38 different CSA-related projects, reaching a total of over 1.6 million beneficiaries (see Appendix F). Of all CSA practices, donors are most likely to fund initiatives relating to conservation agriculture and agroforestry practices (85 percent of donors); horticulture (60 percent); improved land preparation (55 percent); smallholder livestock (40 percent); drought and heat-tolerant seeds (40 percent); and agricultural liming (20 percent).

Geographical distribution of CSA projects: Over 80 percent of the donors and implementers interviewed have funded or supported CSA-related projects in Eastern Province. Only 24 percent of donors and implementers operated projects in the northern Luapula, Northern, and Muchinga Provinces.

Sources: IAPRI 2018; van der Decken 2017; interviews conducted by FAO in 2017 and 2018.

Assuming all mechanisms are rolled out at the same time, to achieve a CSA adoption rate of more than 50 percent of smallholder farmers, the total cost would be US$196 million over six years, the average duration for a investment project, or an average investment cost of US$32.6 million per year. An average six-year project could achieve an NPV of US$63.6 million and an average economic rate of return of 20 percent (see Figure 7.1). Thus, the investment required to roll-out CSA is less compared to recent funding allocations by the GoZ and donors for the agriculture sector, or CSA in particular. Agriculture expenditures available for investment, excluding investment in the Farmer Inputs Support Program (FISP) and Food Reserve Agency (FRA), amounted to approximately US$108 million in 2017. In the same year, donor investment in agriculture and natural resource management amounted to US$173 million (see Box 7.1 for agriculture sector expenditures by the GoZ and donors). Thus for investment to be effective in reducing rural poverty and bolster more resilient agricultural systems not only the quantity of investment plays a role, but also the implementation quality and effectiveness.

Section

8

Conclusion

Climate change and related extreme events are considered as an acute and growing challenge. The CSAIP aims to support GoZ in the process of policy and strategy development to operationalize climate commitments toward a productive, resilient, and low-emissions agriculture sector. Agriculture is viewed as the backbone of the economy and as a sector that can support inclusive structural transformation, poverty reduction, and diversification of the economy away from copper. Climate change, however, is expected to exacerbate the vulnerability of economically marginalized farmer households and slow the growth of the sector. At the same time, the LULUCF sector and agriculture sector together account for approximately 94 percent of the country's carbon footprint. Taken this into account, the CSAIP aims to identify and prioritize key investments and policy actions and to build capacity to operationalize country climate commitments toward a productive, resilient, and low-emissions agriculture sector.

Zambia has ambitious goals and targets for its agriculture sector. At the same time, its goals are conflicting with respect to the question whether further forest land can be converted for agricultural purposes. This calls for further policy harmonization to achieve agriculture sector goals. The vision of the existing agricultural policy frameworks has, as its core, the aim of doubling productivity, while decreasing the country's current overreliance on maize, pursuing diversification, and boosting production and trade, which are expected to bolster food and nutrition security. The assessment showed that at least two strategy documents are in conflict with respect to land use: Zambia's Long-Term Vision for 2030 calls for land under cultivation to expand by 0.9 million ha, whereas the National Policy on Environment incorporates a target of sustainably intensifying land use without converting additional land area into agriculture. To ensure a sustainable achievement of a productive, resilient and low-emission sector, policy harmonization and coordinating activities will be important.

For rural households, CSA has a mostly positive long-term impact. In the short term, farmers face obstacles in the form of high upfront and production costs, and will require financial and other support during the early stages if they are to adopt CSA practices. Of the 10 CSA practices (minimum soil disturbance, residue retention, crop rotation, agroforestry, crop diversification, livestock diversification, commercial horticulture, drought-tolerant seeds, delayed planting, and reducing post-harvest loss), four had a positive impact on household income, food availability, reduction of poverty, and income variability, which is a proxy for household resilience. In the short term, households incur losses due to higher production costs (associated with the need to mechanize, increased labor time), particularly following the adoption of: minimum soil disturbance, residue retention and agroforestry. Interestingly, it is specifically these practices—as well as crop rotation—that can potentially sequester carbon in the soil and can be effective in mitigating climate change. Lastly, optimizing the timing of planting has tremendous potential to enhance household welfare. These findings point towards the need to support farmers in the early stages of adoption by providing: timely access to inputs and supporting the development of markets for mechanization; providing services and finance by aligning subsidies and cash transfer programs with timing of planting; and enhancing capacity building to reduce risk of failure.

Agroecological conditions must be factored in when promoting specific CSA practices, some of which perform better under dry than wet conditions. Practices amenable to dry conditions offer significant potential impact in the event of a drier future climate. A few practices—minimum soil disturbance, residue retention, small-scale horticulture—performed worse under wetter conditions (for instance, AEZ III) than under dry conditions (for example, AEZ I, IIa, IIb), possibly due to increased weed pressure, waterlogging, and lack of drainage. The net incremental benefit to households in Zambia's wetter regions of adopting minimum soil disturbance are notably lower than in drier regions, and for some crops even negative. However, practices such as drought-tolerant seeds, agroforestry and crop diversification show good results under extreme dry and wet conditions, and are suitable for climate adaptation and household resilience building. In testing and developing strategies to implement specific CSA practices, pluralistic participatory extension approaches, including enrolling farmers in participatory trials, should be considered. Other critical strategies and initiatives include: improved and timely agro-weather advisory services, and customized capacity-building support to farmers to optimize planting times and minimize the risks associated with adopting CSA.

At the sectoral level, CSA adoption by between 25 percent and 80 percent of farmers would enhance the likelihood of achieving, and even surpassing, the agriculture sector vision's 2050 targets for crop production, food availability, and trade. Projections through 2050 are driven by increased population, GDP, and increased food demand in Zambia, which are expected to lead to a doubling of crop production. The adoption of CSA practices, particularly reducing post-harvest loss, is expected to further increase production by up to 20 percent compared to conventional practices, and CSA's benefits are expected to be more pronounced under climate change projections. With respect to food availability, conventional agricultural practices are on track to meet the lower limit of national caloric requirements by 2050. With CSA, food availability is expected to increase still further, even under climate change. With respect to trade, the target of doubling net exports by 2050 is feasible in terms of maize and millet, and under extreme climate change scenarios, for cassava. Adopting practices to reduce post-harvest loss and implement conservation agriculture and crop diversification practices would increase Zambia's international competitiveness and act as a driving force for increased net exports in the future. Zambia has the potential to emerge as a net exporter of groundnuts if it pursues agricultural diversification policies, even under climate change projections.

Doubling crop yields, which is a key policy goal of the agriculture sector, will not be achieved either through conventional agricultural practices or through CSA, although the latter will potentially narrow the gap to the desired yield level. Policies and strategies to enhance agricultural productivity are urgently needed. CSA practices with particular potential to narrow the yield gap by enhancing crop yields by 21 percent over conventional practices include reducing post-harvest loss, minimum soil disturbance, and crop diversification. Under climate change, CSA practices have a varying effect depending on the crop and practice. For maize and cassava, for example, minimum soil disturbance promises smaller yield increases; whereas producing maize with drought-tolerant seeds and conservation agriculture or soybeans through crop diversification promise better yields under climate change than with conventional practices, enhancing an already positive yield effect. Productivity increases are an important component of an inclusive process of structural transformation of the agricultural sector. Efforts should be made to address the constraints of productivity growth through the following: targeted agriculture research and development in Zambia or in collaborative research partnerships across the regions; pluralistic participatory extension to support farmers in optimizing their farming practices; and linking farmers to business partnerships such as outgrower schemes; and making production inputs and irrigation and other infrastructure available in a timely manner.

Since crop yield increases are unlikely to meet sector goals, there is a risk that production increases stem from the conversion of forest and savannah into cropland to achieve 2050 crop production targets. CSA practices are expected to curb the necessity of land conversion, but only marginally. Through 2050, considerable land use change is projected, with cropland expected to increase by almost 917,000 ha, and grassland by approximately 1.4 million ha, mostly at the expense of forest area in the productive southern and southwestern regions that form Zambia's AEZ I and AEZ IIa. If so, the agriculture sector vision goal of converting 900,000 ha will be achieved, but the goals of the National Policy on Environment of avoiding land conversions will not be reached. The projected impact of climate change on land conversion is small. Individual CSA practices have the potential to reduce cropland land conversion by between 32,000 ha (through conservation agriculture) and 112,000 ha (reducing post-harvest loss). This reduction in cropland is accompanied by an expansion in grassland driven by an increase in livestock production in the same order of magnitude, so that deforestation is hardly halted. These trends illustrate Jevon's paradox, which states that productivity increases per hectare provide further incentive to expand agricultural land (Alcott 2005).

Trends in land use change put Zambia at high risk of failure to meet its NDC goals of reducing GHG emissions by 25–47 percent by 2030 or 2050, as emissions from agriculture (including crop and livestock) and LULUCF are projected to increase by 57–487 percent in 2050. The impact on emissions of CSA adoption is mixed. Minimum soil disturbance and reducing post-harvest loss can reduce emissions associated with fertilizer use, while residue retention has the opposite effect. There is a negligible average change in overall emissions compared to conventional practices. CSA adoption could reduce emission from land use changes, but only by on average -0.32 percent compared to conventional practices. On the positive side, some CSA practices are expected to enhance soil carbon sequestration, which could be according to a simple calculation example 7 times more effective in reducing tCO_2e emissions than reducing use of nitrate fertilizers. However, data on soil carbon sequestration must be interpreted with caution, since they are based on highly aggregated emission coefficients, and lacks historical and site-specific land use and soil data.

Introducing a low carbon tax on land conversion proves to be an effective policy strategy to achieve mitigation goals and could effectively halt agriculture-related deforestation. However, reducing biomass burning seems the most promising strategy. A carbon tax of US\$10/tCO_2e emissions could reduce emissions from deforestation and other land use change by 99 percent through 2050 compared to a business-as-usual scenario. At the very low price of US\$5/tCO_2e, land conversion would still be profitable. Production and food availability would slightly decrease, by approximately 2 percent, crop yield would slightly increase, and maize imports, for example, are projected to increase by up to 65 percent in certain carbon tax scenarios. While these policies seem promising, actual enforcement would be difficult. In conclusion, while very strict carbon taxes can reduce emissions associated with land conversion and CSA can advance achievement of soil carbon sinks, both of which contribute to achievement of Zambia's NDC targets, it is worth noting that emissions from agriculture and land conversion constitute only 12 percent of total emissions in Zambia today. The largest share originates from the burning of biomass, which has not been modelled in this analysis. If Zambia wishes to reduce its emission significantly, reducing biomass burning and charcoal use must become a policy priority.

While the effect of CSA adoption on agricultural land conversion is small in terms of hectares and GHG emissions, an economic analysis shows its considerable value to public good provision for global society. If reductions in GHG emissions are valued at a shadow price of carbon, the NPV of a large-scale CSA intervention would increase by between 171 percent and 341 percent, or from US$170 million if private benefits are considered, to between US$460 to 750 million. Even a relatively small increase under a low market price for carbon represents an economic value of US$34 million, which would justify exploring the use of carbon finance to support CSA adoption and compensate farmers for initial losses associated with its adoption.

The four most promising CSA practices are crop diversification, commercial horticulture, agroforestry, and reducing post-harvest loss. However, adoption is often constrained by poor access to finance and market access and inadequate levels of capacity building and skill development. Despite donor support and public sector involvement, adoption of these four practices remains low. Promising CSA strategies were identified based on a ranking across household and sectoral indicators. Other practices, while also promising, have larger trade-offs. Livestock diversification, for instance, offers great benefits in terms of household resilience and food security and should be explored, but may also require expansion of grassland at the expense of forests and will increase methane emission levels. Some of the obstacles that will need to be addressed to spur CSA adoption are: low knowledge and capacity to adopt CSA practices; poor access to finance to overcome upfront investment and labor hire constraints; inadequate access to market infrastructure and input and output markets.

Public resources should be allocated to crowd-in private sector finance and maximize finance to achieve agriculture sector goals and the sector's potential to contribute to Zambia's structural transformation. CSA has significant potential but there is still room for improvement, for instance with respect to increasing yields, reducing land use change, and achieving other development goals including: inclusive employment, improved nutrition, and reducing incident and rural poverty. A complicated question arises: what type of public investment will address the adoption constraints of CSA and can promote private sector investment from farmers, traders, agribusinesses, and processors or financing institutes, all of which can take advantage of Zambia's agriculture opportunities? Eight innovative and proven mechanisms are presented that can enhance CSA adoption, and public actions have been identified that can spur private sector involvement.

Of eight innovative mechanisms, establishing business partnerships with rural communities, participatory, integrated landscape management approaches, and farmer field schools have the potential to address critical enabling environment constraints and achieve high rates of return on investment. The analysis assessed attributes of several mechanisms, their expected economic benefits, and public sector interventions needed to support their establishment. Supporting business partnerships with rural communities and outgrower schemes for commercial horticulture production seem most promising for overcoming enabling environment constraints. Considering economic indicators and effectiveness to address constraints to CSA adoption, business partnership with

Box 8.1 Policy recommendations

The analyses of CSA practices under various scenarios and assessment of mechanisms to support CSA adoption show that **business partnerships with rural communities** which build on environmental sustainability as business strategy, **farmer field schools** to enhance community-based learning and technology dissemination, and **participatory integrated landscape management approaches** seem promising and profitable mechanisms to support the development of a productive, resilient, and low-emission agriculture sector. These can be supported by several policy actions:

1. Support farmers with **improved access to inputs and finance**, specifically in early stages of CSA adoption until benefits start to be realized. Support the development of markets for mechanization, innovative ICT-based solutions including agro-weather services for timely decision-making, and access to improved production inputs and seed varieties suitable for varied agroecological zones.

2. Support **agricultural research**, regional collaboration in research, participatory testing of CSA technologies to enhance their potential to increase crop yields, across and especially wet agroecological conditions. Support the advancement in the development and multiplication of seed varieties that are appropriate for rainfed production systems, in particular in the legume seed sector and short-duration maize seeds.

3. To increase agribusiness participation in the sector, **a range of policy actions** seem promising: (i) support feasibility, as well as risks and vulnerability assessments, to identify entry points and challenges; this should include an assessment of risk- and cost-sharing mechanisms which provide an understanding where the incentives align between the public good element of CSA and private sector motive; (ii) seek dialogue with agribusinesses about resulting investment opportunities; (iii) review the legal and regulatory framework to identify reform requirements and strengthen the business environment; (iv) provide opportunities for human capital development, capacity building and extension services for agriculture sector actors.

4. Support **operationalization of holistic landscape management approaches by harmonizing policies and supporting cross-ministerial collaboration** across the agriculture, environment, water and energy sector, and across administrative boundaries. Landscape approaches include climate-smart crop, livestock and forest management and have the potential to reduce alarming rates of land conversion for agriculture as well as addressing issues of biomass burning and charcoal production, which are key for Zambia's carbon footprint.

5. Pursue the **positive agriculture sector reform path of converting FISP into an e-voucher program, which supports agricultural diversification and adoption of short-duration varieties** targeted to Zambia's agroecological zones. The analysis shows the benefits of crop diversification into legumes, but also the need to improve the timing of planting or make short-duration varieties available to enhance crop yields.

6. Further support **development of market infrastructure such as rural storage facilities** and enable greater private investment in storage. Private investment may occur where production levels are high and stable and where access to border markets is feasible. In places where these conditions are not met, public investment may be required. In addition, training and collective action on improved post-harvest management bears a high potential to achieve CSA triple-benefits.

communities could facilitate access to markets, finance and capacity building, and demonstrate an economic internal rate of return on investment of 31 percent. Farmer field schools and integrated landscape management approach address two constraints but have relatively high rates of return of 39 percent and 36 percent, respectively. Specifically, participatory integrated landscape approach can achieve high return on investment and provide incentives to work across sectoral silos between agricultural, environment and water sector and support policy harmonization. These approaches should be considered in future government and donor programs.

Box 8.2 Knowledge gaps and further research

In the course of developing the CSAIP following areas were identified which need further attention:

Institutional capacities can be strengthened using these methods:

(i) Conduct an ***assessment of institutional capacities*** to better address bottlenecks in project implementation. Agriculture economic research is conducted but implementation success seems to be varied.

(ii) Develop a ***sector-wide monitoring and evaluation framework*** to document success in promoting CSA and implementation of agriculture investment plans.

(iii) Produce an ***inventory of projects***, spending, beneficiaries reached, and outputs.

A variety of quantitative assessments are recommended, as follows:

(i) ***Climate change impact assessments***, which are important to understand climate dynamics, and climate-economy interactions, are inherently uncertain and must be interpreted with caution.

(ii) ***Research the impact of CSA practices*** on crop yield or GHG emissions in a spatially explicit manner across Zambia. Little experimental evidence is available across Zambia. Mitigation through soil carbon sequestration and related data needs remain an area for future research.

(iii) ***Further research on biomass burning for charcoal***—a major source of GHG emissions that critically affects the achievement of NDC targets. Further study on introducing improved cooking solutions in urban and rural households and country-wide impacts is needed.

(iv) Develop a ***model that considers long-run anthropogenic climate change and includes climate variability***, such as extreme weather events—floods, droughts, and hurricanes—which are expected have a significant negative impact on future economic and agricultural development in Sub-Saharan Africa (Ahmed et al. 2011; Thurlow et al. 2012). Modeling the effects of year-by-year climate variations requires the use of a stochastic modelling approach, which is currently under development.

Almost all delivery mechanisms show positive economic rates of return; rolling them out to more than 50 percent, of smallholder farmers, would require an annual public sector investment of US$32.6 million over six years. If rolled out to 118,000 beneficiaries, for example, expected rates of return on investment range from 11 percent (weather index insurance) to 39 percent (farmer field school). A roll out of all mechanisms at the same time would yield a rate of return on investment of 20 percent and an economic net present value of US$63.6 million. The proposed annual investment of US$32.6 million over 6 years is less than recent annual GoZ and donor funding for the agriculture sector, which was estimated around US$108 million and US$118 million, respectively, in 2017. While investment quantity is important, implementation quality and effectiveness have to be ensured to see desired results for a climate-resilient agriculture sector and sustained poverty reduction among smallholders in rural areas.

The report concludes with eight recommendations, which are ranked by feasibility and relevance (Box 8.1), as well as knowledge gaps (Box 8.2) for which further research is needed.

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Appendix A: Policy Frameworks

Table APP 1: Overview of policy frameworks relevant to climate-smart agriculture in Zambia

Policy framework	Overview	Goals for agriculture sector	Measurable indicators	Strategies suggested
The National Long Term Vision 2030 (2006)	Provides an account of Zambia's development since independence and scrutinizes the driving factors of each sector's performance. It concludes that the large majority of farmers are dedicated to subsistence farming and have not significantly benefitted from liberalization reforms, partly due to remoteness from major markets. **Vision for the agricultural sector:** An efficient, competitive, sustainable and export-led agriculture sector that assures food security and increased income by 2030	• Increase agricultural productivity and land under cultivation by 2030 • Increase exports of agricultural and agro-processed products by 2030 • Preserve the agricultural resource base by 2030 • Increase fish and livestock populations • Increase agricultural machinery	• Agriculture 10.08% of GDP • Increase cultivated land by 900,000 hectares • Increasing land under irrigation to 400,000 hectares • Increase agricultural machinery • Increase livestock population to 6,000,000 • Increase fish production to 300,000 MT	• No specific strategies suggested for the agriculture sector
The National Adaptation Programme of Action on Climate Change (2007)	Based on a comprehensive assessment of climate-related hazards to the economy. It recognizes droughts, floods, extreme heat, and shorter rain seasons as the major challenges to productivity and resilience of the agriculture sector and proposes pragmatic counter-actions such as income diversification, increased use of irrigation systems, and improved post-harvest storage infrastructure.	• Diversify incomes to allow for purchasing and trading of food • Shift agricultural production to higher land to reduce flood and heat risk • Gather and sell more wild food	• Establish 2 disease-free zones by 2010	• Promote irrigation and efficient use of water • Improve post-harvest storage and marketing • Develop dams and dip tanks • Sustainable supply of feed • Promote aquaculture
The National Policy on Environment (2007)	The National Policy on Environment was developed to synchronize and work across individual sectoral strategies that pertain to Zambia's environment and natural resources (e.g., agriculture, mining). The NPE, therefore, aims to fill a policy void to be one holistic, overarching strategy to implement the Millennium Development Goals for sustainable development by developing natural resources to spur development while conserving important resources and ecosystems.	• Sustainable crop and livestock production • Employ ecologically appropriate production techniques • Institute an appropriate institutional framework for sustainable development • Reduce GHG emissions	• No measurable indicators proposed	• Sustainably intensify land use without converting additional land area into agricultural land • Develop a comprehensive agricultural policy that incorporates components of conservation agriculture and does not increase agricultural encroachment • Educate and train extension workers and farmers on conservation issues, particularly soil quality
National Climate Change Response Strategy (2010)	Seeks to develop a multi-sectoral strategy for Zambia in line with UNFCCC's objective to "stabilize greenhouse gas concentrations in the atmosphere." It serves as a primarily economic strategy, encompassing the Nationally Determined Contribution and the National Agriculture Policy.	• Increase agricultural production and food security under the changing climate • Increase farmers' capacity to respond to climatic shocks on the farm scale • Build infrastructure on small-holder farms to increase production capacity • Diversify rural and small-holder incomes	• No measurable indicators proposed	• Support Zambia's early warning system. • Diversify crops, fisheries, and livestock. • Improve soil quality through conservation agriculture, further supported by government-provided fertilizers and lime. • Government and private sector investment in on-farm infrastructure including irrigation, water storage facilities, and fish hatcheries. • Drought-resistant varieties of crops and livestock.

continued

Table APP 1 Continued

Policy framework	Overview	Goals for agriculture sector	Measurable indicators	Strategies suggested
National Agricultural Policy 2012-2030 (2011)	After a review of the previous NAP (2004-2015), the Ministry of Agriculture and Cooperatives developed a plan for the agricultural sector in line with the Vision.	• To increase the annual growth rate of the real GDP • To increase the value and growth rate of crop exports • To contribute to reduction of poverty and food insecurity	• Attain 10% economic growth rate 2021-2030 (economy wide)	• Promote sustainable increase in agricultural productivity of major crops • Improve agricultural input and product markets so as to reduce marketing costs of agribusiness, including small-scale farmers and farmer groups; • Increase agricultural exports to preferential markets
National Livestock Development Policy (2012)	The Livestock Development Policy outlines the roles, the vision and focus of various stakeholders in order to contribute to increased production and productivity of the livestock sub-sector thereby increasing food security and income, and reducing poverty.	• Attainment of food security for the majority of households • Increased Livestock sector contribution to total foreign exchange earnings • Increased livestock contribution to GDP. • Increased incomes for those involved in the agricultural sector	• No measurable indicators proposed	• Targeted subsidies for control diseases of national economic importance • Diversification of the livestock base • Enhance market support • Public-private partnerships, with the public sector focused on small-scale farmers and the private sector investing in credit marketing and provision • Technology dissemination, particularly to small-scale farmers
National Agriculture Investment Plan 2014-2018 (2013)	The National Agriculture Investment Plan was crafted under the Comprehensive Africa Agriculture Development Programme and outlines specific investment opportunities for the Zambian agricultural sector, with an emphasis on pro-poor agricultural-led economic development.	• Increase the value and growth rate of crop exports to preferential markets • Increase the annual growth rate of agricultural GDP and agriculture's share of overall GDP • Increase production of staple foods, including fruits and vegetables, for own consumption and the surplus for income generation	• Increase in agricultural exports as a percentage of non-traditional exports from 41% in 2011 to 55% by 2018 • Increase cereals production from 3.2 million tonnes to 6.0 million tonnes by 2018 • Reduce chronic malnutrition among children under five from 45% to 30% by 2018 • Reduce soil erosion per hectare from 20 tonnes to 10 tonnes by 2018	• Support farmer cooperatives and increase funding for extension workers • Promote low-cost farm inputs such as inorganic fertilizer • Diversify crops to include oil seeds (e.g., sunflower) and fruits/vegetables to provide a balanced diet and supplemental income, particularly focusing on crops that increase soil quality • Increase the number of farmers who have the title to their land
Zambia's Nationally Determined Contribution to the 2015 Agreement on Climate Change (2015)	Zambia determined its intended reduction in GHG emissions, in line with the 2015 Agreement on Climate Change from the United Nations Framework Convention on Climate Change (UNFCCC).	• Reduce GHG emissions from the agricultural sector • Improve soil productivity leading to improved crop productivity • Create agricultural job opportunities and alternative livelihoods contributing to reduced rural poverty	• Reduce 38,000 Gg CO_2e emission conditional on international support of US$35 billion; reduce 20,000 Gg CO_2e under the domestic efforts with limited international support. This translates into a reduction potential of 25% and 47% against 2010 as the base year, respectively	• Reduced fertilizer use and less turning of soil • Soil carbon sequestration • Rural biogas plants

Table APP 1 Continued

Policy framework	Overview	Goals for agriculture sector	Measurable indicators	Strategies suggested
Zambia National Strategy to Reduce Greenhouse Gas Emissions from Deforestation and Forest Degradation (REDD+) (2015)	Forest covers approximately 60% of Zambia's land area, although Zambia has one of the top 10 deforestation rates of any nation in the world. The UNFCCC developed REDD+ as a mechanism to reduce deforestation in developing countries. This national plan represents the working relationship between the Government of Zambia and the UNFCCC to reduce emissions from deforestation and land use change in Zambia.	• Reduce GHG emissions by improving forest and land management • Increase adoption of agricultural practices that mitigation carbon emissions • Regulated systems for wood fuel are in place	• No measurable indicators proposed	• Develop a climate-smart agricultural practice framework • Use incentives to increase adoption of climate-smart technologies and practices • Promote good agricultural practices related to reduced emissions from agro-processing dependent on use of wood fuel from indigenous forests
Seventh National Development Plan 2017-2021 (2017)	Every five years, the Government of Zambia undertakes a planning process to define the roadmap to development for the coming years. This document builds toward the Vision 2030 of having Zambia as a "prosperous, middle-income country by 2030" and outlines specific development goals and strategies for each sector of the economy.	• Build a diversified and export-oriented agricultural sector focused on crops, livestock, and timber • Improve water resources development and management • Improve access to finance for production and exports • Diversify small-holder farmers	• 10%+ share of GDP is agriculture by 2021 • Agriculture accounts for 20% of new jobs generated by investments by 2021 • Agricultural, fisheries, and fishing export value of $931M by 2021 (7.8% of total export value)	• Emphasize high-value export crops such as cashews, coffee, sugar, and tea • Build rural infrastructure to increase small-holder farmers' access to markets • Invest in rural irrigation • Develop the ICT system • Develop livestock and fisheries breeding centers

Appendix B: Results of First Stakeholder Workshop

B.1 Developing a Normative Vision for the Agriculture Sector in Zambia

Goal(s) for the session:
Develop a one-sentence visioning statement for each pillar of CSA (productivity, resilience, mitigation co-benefits) out to 2050.

Methodology:
Workshop participants were divided evenly into three groups (one per CSA pillar). Workshop facilitators asked participants to identify words that were associated with the CSA pillar. For each word, facilitators asked participants to write a sentence about their hope for the CSA pillar associated with that word. The sentences were clustered and combined by the group into one cohesive vision.

Results:
- ***Productivity:*** "By 2050, double profits and yields through diversification of crops (beyond maize), while ensuring household food and nutrition security."
- ***Resilience:*** "By 2050, have an agriculture sector that is diversified in crop production, age, and gender, and which is able to cope with economic and climatic shocks through enhanced capacity and policy."
- ***Mitigation:*** "By 2050, Zambia's agricultural sector will increase productivity while maintaining a low ecological footprint."

Discussion:
- Participants felt that low productivity could be overcome for farms by 2050, to the extent that the sector could become twice as productive.

- There was an important distinction between commercial and small-scale farmers, and the discussion was around whether the goal should focus on one scale or another; participants ultimately decided that not differentiating between the scales allowed for the commercial sector to make up for any lack of productivity gains of small-scale farmers.

- The group highlighted both profits and food security as measures of success because both were critical indicators of development—food security alone indicated a level of hand-to-mouth poverty, but coupled with profits indicated a level of economic empowerment.

- Diversification is seen as a key tool both for ensuring that farmers are insulated from market and climatic shocks (resilience) and for increasing small-holder farmers' standard of living, measured by both food security and incomes (productivity).

- Although mitigation of GHGs is understood to be important, increasing productivity in the face of climatic and market uncertainties is the clear priority for the sector.

B.2 Prioritizing Goals to Work Toward Vision

Goal(s) for the session:

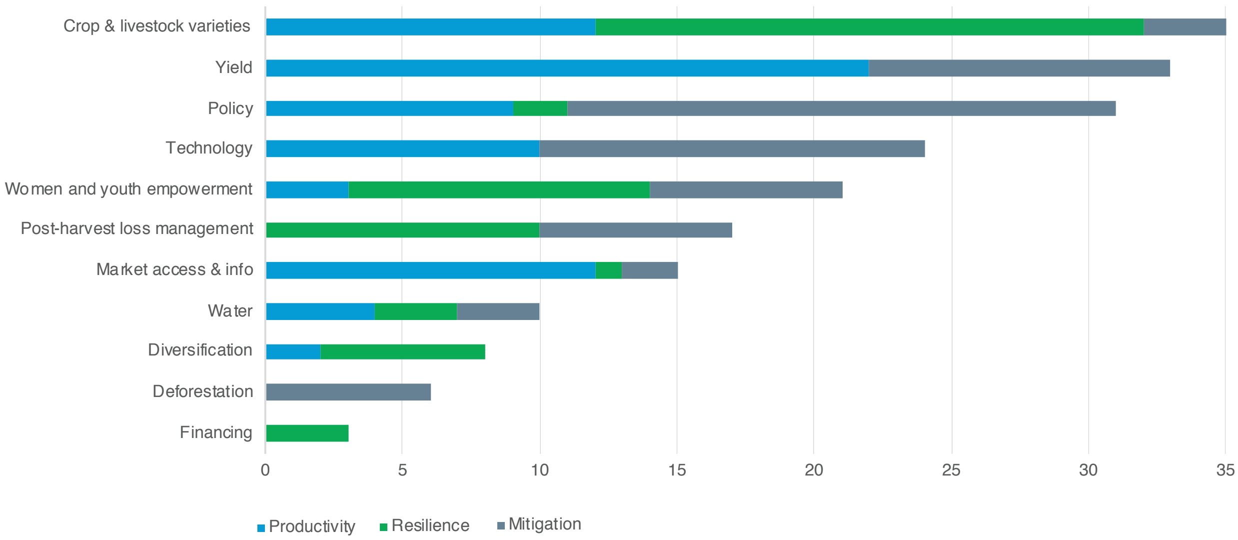
Identify specific, measurable goals that would allow Zambia to achieve the vision for each CSA pillar.

Methodology:

Workshop participants remained in assigned groups by CSA pillar. Each workshop group identified between 20 and 35 goals with end date 2050 for their CSA pillar; the goals were then clustered thematically. In addition to goals identified by workshop participants, the workshop moderators contributed measurable targets that were part of national plans for Zambia (e.g., the 7th National Development Plan). Workshop participants were then allowed to vote using stickers on their favorite goals, across all three CSA pillars.

Results:

Number of votes for goals, by category:



Top three specific goals, by CSA pillar:

Productivity	Resilience	Mitigation
• Promote the development and use of stress-tolerant varieties among 30% of small holder farmers • Double yields for maize and food legumes for small holder farms • Make market information readily available through ICT	• 60% of arable land uses drought-resistant crops • Post-harvest losses are reduced to 5% • At least 60% of men, women and youth involved in agriculture belong to functioning savings groups	• Increase investments in extension and agricultural R&D to 15% of the agricultural budget • Increase the adoption of CSA practices by at least 30% • 75% of Zambian women and youth are participating in modern farming to achieve intensification

Discussion:

As with the visioning exercise, many workshop participants, particularly in the productivity group, focused heavily on the scale at which these goals would be applied. The commercial sector, for example, may try to double exports, while small holder farmers will try to double productivity of their maize plots. All three groups had goals related to women and youth participation in the sector, although participation of women in the agricultural sector is already high.

B.3 Prioritizing Goals to Work Toward Vision

Goal(s) for the session:

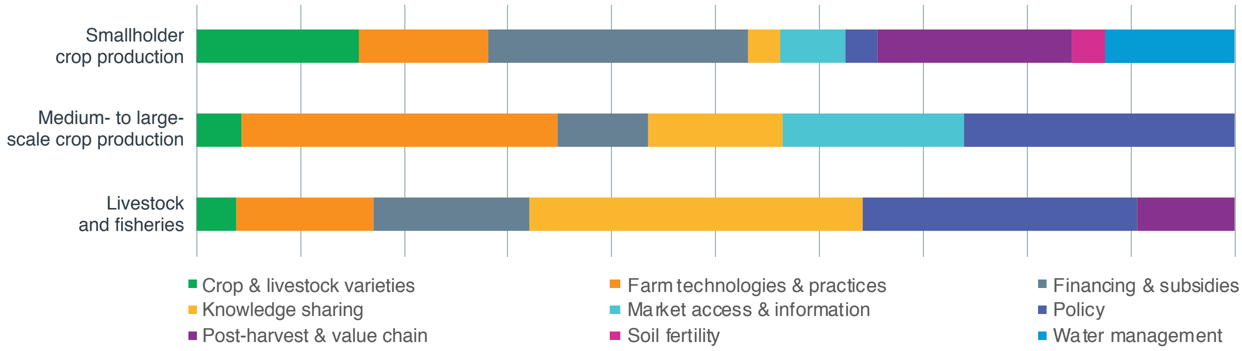
Identify a list of specific strategies that are necessary in order to achieve the sector goals.

Methodology:

Participants were placed into three different groups to address both variation in commodities and scale within Zambia's agricultural sector: (1) smallholder crop production, (2) crop production of medium- to large-scale farmers, and (3) livestock and fisheries (across all scales). For each group, participants were asked to identify the extent to which each proposed strategy had already been tried and the extent to which it had been successful. After strategies were identified, the workshop participants were invited to vote on the most promising individual strategies using stickers.

Results:

Relative weight of strategic engagement method, by commodity/scale:



Top four specific strategies, by commodity/scale:

Smallholder crop production	Medium- to large-scale crop production	Livestock and fisheries
• Breeding for high-yield varieties • Gendered enterprise model to the value chain • Pluvial gardening in ponds • "Pass on the Gift" model (i.e., Heifer International model)	• Research & development of new crop varieties • Education of farm workers to increased skilled manpower • Specialized extension services • Renewable energy for agricultural bioslurry	• Outgrower programs • Micro-finance policy and legislation • Train staff in animal husbandry and pasture management • Adopt a public-private partnership approach with NGOs

Discussion:

Many groups highlighted that this was not the first strategy exercise they had been a part of, and many of the strategies had already been tried, but that the bottleneck was with regards to scaling. Many participants felt that NGOs have experimented on the ground, but that strategies were not being widely adopted. One key constraint identified was that actors on the ground were not aware of what funds were available for various projects and were therefore not scaling projects. Another was the limited capacity of the extension workers to help introduce and scale up new projects. Some practices, like liming, have been shown to be effective, but were too expensive to be widely adopted.

B.4 Drivers of Uncertainty and Scenarios of Future Worlds

Goal(s) for the session:

Identify a list of exogenous drivers of uncertainty and quantify the extent to which they impact Zambia's ability to achieve its goals.

Methodology:

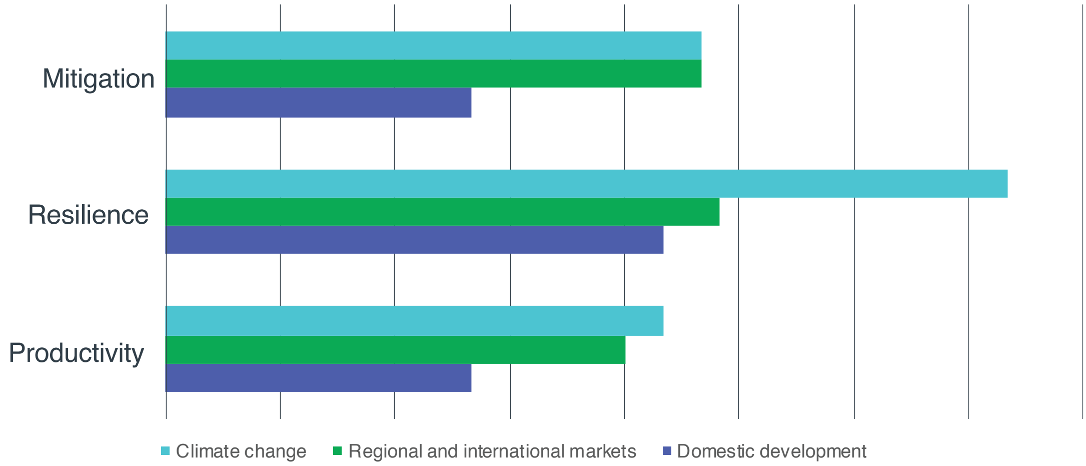
Participants were asked to identify a list of exogenous factors that could impact Zambia reaching its goals. The factors were then grouped into general trends that co-vary with each other. For each "driver of uncertainty," workshop participants were asked to quantify the extent to which the uncertainty impacted Zambia's capacity to achieve the goals previously identified in the workshop on a scale from 0-3. For example, the workshop participants were asked, "To what extent (0-3) does rainfall variability impact small-holder farmers' ability to double maize and legume yield by 2050?"

Results:

Brainstormed drivers of uncertainty, grouped into clusters:

Climate change	Regional & international markets	Domestic development
• Rainfall variability • Temperature variability • Pests and diseases	• Global markets and commodity prices • External political stability (i.e., regional governments) • Availability of external funds	• Internal political stability (i.e., the Zambian government) • Changing dietary patterns

Relative impact of uncertainty drivers on CSA pillars:



Discussion:

During this session, participants focused heavily in conversation on the extent to which external political and market forces would impact their ability to achieve their goals. For example, one participant identified how commodity prices of sugar, for example, would hurt small-scale farmers who are just beginning to grow sugar. Similarly, a refugee crisis in neighboring Democratic Republic of the Congo could increase the number of mouths to feed and increase national malnutrition. However, according to the numbers, climate change was identified by all three groups as the largest wild card in achieving the stated goals. In particular, the resilience group strongly connected climate change impacts with reaching their goals.

Appendix C: Household-level Econometric Assessment

C.1 Methodological Approach

This section expands on a methodological summary provided in Section 3.2.

A difference in difference (DiD) approach is used to measure the causal effect of early CSA adoption on welfare indicators, while addressing self-selection bias. The DiD estimator is used to assess the impact of CSA adoption on households that did not adopt the practice in the first wave of the survey, but did adopt in the second wave. The choice of DiD is based on the assumptions that farmers "self-select" themselves into being in the group of CSA adopters, according to a number of specific characteristics. Households which have adopted CSA are expected to differ systematically from those that have not. Failing to control for the selection leads to biased results (Rosenbaum and Rubin 1983). The empirical strategy takes advantage of an inverse weighted DiD regression model. This approach is expected to remove the selection bias through a doubly robust estimation of the causal effects of the treatment (Hirano et al. 2003; Bang and Robins 2005). To the extent that the CSA investments are captured either by dichotomous or continuous variables, the inverse probability weights have been obtained using either a propensity score (Rosenbaum and Rubin 1983) or a general propensity score analysis (Hirano and Imbens 2005), accordingly.

The DiD estimator mimics an experimental research design using observational study data, by studying the differential effect of a treatment on a "treatment group" versus a "control group." The observational study data are two sets of the Rural Agricultural Livelihoods Surveys (RALS) household surveys for 2012 and 2015. In the DiD, the adopter of a CSA practice is the treatment group. The adopter is defined as having adopted a CSA practice after the 2012 survey and before the 2015 survey.

The causal effect has been estimated using a Weighted Least Squares procedure whereby the weight attributed to each observation is the inverse of the probability of the treatment (Imbens 2000; Bang and Robins 2005; Naimi et al. 2014). More weight is given to the treatment cases that resemble the controls, since they are more relevant. Similarly, since the control cases that look like those that have gotten the treatment are more relevant, they are weighted more. The baseline specification has been estimated using a DiD estimator, which enables controlling both for the unobserved time-fixed heterogeneity and the change in trend between treated and control. The common trend assumptions cannot be tested as only two survey waves are available:

Equation 1:

$$Y_{i,d} = \phi + \alpha D2013_i + \gamma_1 CSA_{id} + \gamma_2 (D2013_i * CSA_{id}) + \sum \beta X_i + \epsilon_{id}$$

where Y_i is a vector of selected outcomes, CSA is the treatment, $D2013$ is the time dummy identifying the follow-up survey round, and X_i is a vector of exogenous explanatory variables. In addition, ∅ and ∊ are the constants and the random distributed error terms, respectively. In this framework, the parameter of interest, γ_2, estimates the average treatment effect of the CSA investment. To exclude the confounders, the analysis considers only households not adopting any CSA investment at the baseline and the follow-up (control group) and households that have invested in CSA at the follow-up (treatment group). However, the limitation of this approach is that the sample of adopters is restricted to only recent adopters, that is, those who adopted between 2012 and 2015.

To capture impact of long-term adoption of CSA, an OLS regression model was employed to show the conditional correlation between long-term CSA adopters and welfare indicators. The impact estimates using the DiD model are restricted to early adopters of the practice. To address this limitation, an OLS model is used to examine associations between the welfare variables of interest and adoption of particular CSA practices. Under this second model, the adopters of a CSA practice are defined as households that adopted the practice in both waves of the survey. While this approach does not allow for an assessment of the causal impact of adoption of a CSA practice, as does the DiD approach, it provides insights into relationship between longer-term adoption and key welfare outcomes. The second specification (Equation 2) uses the same group (Wooldridge 2010) and tests the impact of CSA adoption for the households that have experienced a rainfall shock:

Equation 2:

$$Y_{i,d} = \phi + \alpha D2013_i + \beta_1 SHOCK_{id} + \beta_2(D2013_i * SHOCK_{id}) + \gamma_1 CSA_{id} + \gamma_2(D2013_i * CSA_{id}) + \theta_1 SHOCK * CSA_{id} + \theta_2(D2013_i * SHOCK * CSA_{id}) + \sum \beta X_i + \epsilon_{id}$$

In this case, the variable $SHOCK$ identifies the exposure to a rainfall shock during the reference period. In this framework, the parameters β_2 and γ_2 are the stand-alone treatment effects of the shock and the investment, respectively. Further, θ_2 is the incremental treatment effect of a specific CSA investment on the subsample of households that experienced a shock. The limitation of this second approach is that selection bias cannot be controlled for, leading to concerns about endogeneity. Thus, the results of the second approach are treated as conditional correlations rather than casual impacts.

To test the sensitivity of results relative to climate shocks, the analysis approximates the impact of rainfall shocks using a Standard Precipitation Index (SPI). SPI was developed for defining and monitoring drought. It enables determining the probability of a drought at a given time of interest (temporal resolution) for any rainfall station with historic data. The index can also be used for identifying flood risk. It is based on the cumulative probability of a given rainfall event which is calculated using historical rainfall data. The data, at resolution of a weather station, is smoothed through a moving width before being fitted to a gamma distribution through a maximum likelihood estimator. The baseline analysis sets the threshold for anomalous dry periods at -1 and 1 for anomalous wet periods. The rainfall cumulative distribution is calculated for a time span of six months, covering the entire agricultural season from November to April. The dummy variables identify events which have a low probability to occur in medium accumulation periods that may not have disruptive consequences.

Sensitivity analysis was conducted for all models. The climate sensitivity analysis was carried out re-estimating the models using all possible combinations between the thresholds to identify shocks and the time span to calculate the cumulative distribution of rainfalls. By reducing the accumulation period to three months covering the planting and the flowering season (from November to January), the shock index captures infrequent rainfall events that reduce soil moisture and water flow in smaller creeks. Moreover, by setting the thresholds at -1.5 and 1.5, the index captures extreme dry or wet periods that affect streamflow and reservoir storage. Since the exact relationship between accumulation period and impact depends on the natural environment (e.g., geology, soils) and human interference (e.g., existence of irrigation schemes, infrastructure), the estimated treatment effect is expected to change with the indexes.

C.2 Data Sources

This section expands on a data sources summary provided in Section 2.3.

The analysis used the Rural Agricultural Livelihoods Surveys (RALS) for 2012 and 2015. These surveys were collected by the Zambia Central Statistics Office (CSO) in collaboration with the Ministry of Agriculture, Michigan State University, and the Indaba Agricultural Policy Research Institute (IAPRI). They are nationally representative of smallholder households in Zambia (cultivating <20 hectares). Among other things, the survey contains georeferenced information on sociodemographic characteristics, farm management practices, access to credit and assets, access to markets and infrastructure, information availability, input used, and output produced. The survey consisted of 7,254 households in 2012 and 7,934 in 2015. In 2015, 680 new households were added from different clusters in Lusaka, Eastern, and Muchinga Provinces.

Daily rainfall data in high resolution is available on a daily basis. The RALS data permits controlling for geographical and biophysical conditions, and therefore it can be augmented with geospatial rainfall, soil quality, and agroecological information to control for the geographical and physical conditions. Rainfall data have been extracted from the Africa Rainfall Climatology version 2 (ARC2) of the National Oceanic and Atmospheric Administration's Climate Prediction Center. This daily data is based on the latest estimation techniques and has a spatial resolution of 0.1 degrees (~10km). The dataset contains rainfall information at 10-day intervals over the 1983-2015 period and describes the historical rainfall pattern of each geographic location at the weather station resolution. This allows for the creation of georeferenced rainfall variables to identify anomalous wet and dry conditions, which are used in the analysis to assess the impact of climate events on adopters and non-adopters of particular CSA practices.

Data on maize seed varieties used by smallholders during the 2012 and 2015 farming seasons was collected from major seed producers based in Zambia. The information collected included the recommended "not to exceed" planting date by AEZ level, and whether the seed was bred for drought and/or heat tolerance. In total, information on 74 varieties from five companies was collected.

C.3 Detailed Results

This section expands on an overview of high-level results provided in Section 4; it provides summary results of the econometric analysis of CSA-specific impacts on key welfare indicators (Table APP 2 and Table APP 3) and summary of the sensitivity analyses, for the estimated impact of CSA strategies under abnormally wet and dry conditions (Table APP 5 and APP 6). Table APP 4 is based on a combination of qualitative information gathered through stakeholder consultations and literature review, as well as empirical results where available. The DiD estimations aim to assess the average treatment effect and the estimation of the incremental impact of the treatment on the sub-sample of household farmers who have experienced a rainfall shock (obtained through a triple difference estimator) and included following control variables: female household head; household head's highest level of education completed; number of household members in adult equivalent; dependency ration; agriculture asset wealth index normalized; total number of animals; whether household cultivates only one crop; household is part of a cooperative, farmer, women, savings, loan group; participation in the FISP; smallholder household; commercialization index; distance to roads, markets, FRA (log of distance in kilometers); medium number of traders; information availability on CSA index; household applies inorganic fertilize; agroecological zones. The estimation results of each model, that is, DiD, OLS and assessment of climate sensitivity for different rainfall shocks (as obtained by modifying the accumulation period and/or the identification thresholds) is available upon request in the form of a Background Paper.

Table APP 2 Estimated impact of short-term adoption of CSA strategies on a range of household welfare indicators using a DiD approach

	Crop income	Crop income variability	Gross income	Gross income variability	Poverty	Food insecurity
Minimum soil disturbance	-0.011	0.012	-0.03	-0.003	0.020*	0.002
Residue retention	0.006	0.041	0.031	-0.174***	-0.023	0.039
Legume rotation or intercropping	-0.011	-0.020	0.019	-0.029	-0.010	0.010
Commercial horticulture	0.096***	-0.015	0.067***	-0.048***	-0.017*	0.011
Agroforestry	-0.048	0.017	-0.052	0.023	0.027	0.031
Crop/livestock integration	0.006	0.008	0.026	-0.020	-0.046**	0.019
Livestock diversification	-0.000	0.000	0.000	0.001*	0.000	0.000**
Delayed timing of planting	-0.000	-0.042	-0.031	-0.027	0.007	0.014
Use of drought-tolerant maize seeds	0.030	-0.021	0.018	-0.015	-0.016	-0.002
Use of heat-tolerant maize seeds	0.022	0.007	0.032	-0.024	-0.011	-0.006
Crop diversification	0.003***	-0.001	0.003***	0.002	0.001	0.001

Sources: Estimation by FAO, using RALS 2012 and 2015 data.
Note: * p<0.10; ** p<0.05; ***p<0.01: the level of statistical significance in results increases with the number of (*). The complete estimation results with the full range of control variables are available upon request.

Table APP 3 Estimated impact of longer-term adoption of CSA strategies on a range of household welfare indicators using an OLS approach

	Crop income	Crop income variability	Gross Income	Gross income variability	Poverty	Food insecurity
Minimum soil disturbance	0.554***	-0.474	0.630***	-0.487***	-0.228***	-0.110
Residue retention	0.062*	0.034	0.009	-0.036	-0.002	0.008
Legume rotation or intercropping	0.222***	-0.234	0.025	-0.154	0.031	-0.073
Commercial horticulture	0.300***	-0.334***	0.043	-0.154**	0.005	0.044
Agroforestry	-0.053	-0.493*	0.054	-0.459**	-0.009	0.233
Livestock diversification	0.115	-0.151	0.204	0.062	-0.071	-0.281***
Delayed timing of planting	-0.087**	0.463***	-0.086***	0.003	0.016	-0.018
Use of drought-tolerant maize seeds	0.343***	-0.363***	0.181***	-0.146**	-0.099***	-0.144***
Use of heat-tolerant maize seeds	0.348***	-0.612***	0.220***	-0.184**	-0.144***	-0.175***
Crop diversification	0.006***	-0.003***	0.002***	-0.003***	0.001	0.000

Sources: Estimation by FAO, using RALS 2012 and 2015 data.
Note: * p<0.10; ** p<0.05; ***p<0.01: the level of statistical significance in results increases with the number of (*). The complete estimation results with the full range of control variables are available upon request.

Table APP 4 Assessment of the impact of CSA strategies on alternative development indicators

	Household income	Job creation	Likelihood of adoption by poor farmers	Nutrition	Value chain development
Minimum soil disturbance	0	+	-	0	++
Crop residue retention	+	0	-	+	0
Legume rotation or intercropping	0	++	+	+++	++
Commercial horticulture	++	++	0	++	++
Agroforestry	+	0	+	+	+
Livestock strategies	++	++	-	+++	+++
Delayed planting	++	++	+	++	++
Use of drought- and heat-tolerant maize seeds	+++	+	0	+++	+
Crop diversification	++	++	+	+++	+++

Sources: Elaborated by FAO
Note: (-)=negative, 0= neutral, +=low positive, ++=medium positive, +++=high positive

Table APP 5 Estimated impact of CSA strategies under abnormally dry conditions

	Crop income	Crop income variability	Gross Income	Gross income variability	Poverty	Food insecurity
Minimum soil disturbance	-0.000	-0.000	0.000	0.000*	-0.000	0.000
Residue retention	-0.160	-0.045	-0.295	-0.104	0.071	-0.236***
Legume rotation or intercrop	-0.037	-0.089	0.082	-0.064	-0.031	-0.104*
Commercial horticulture	0.211**	-0.246	0.251**	-0.148	-0.191***	-0.160**
Agroforestry	0.000	-0.000	0.000	-0.000	0.000	-0.000***
Crop/Livestock integration	0.000***	-0.000	0.000	-0.000	-0.000***	0.000
Livestock diversification	0.001	0.003	-0.000	0.007*	0.000	-0.005**
Delayed planting	-0.085**	7.826***	-0.082***	0.005	0.014	-0.020
Use of drought tolerant maize seeds	0.365***	-0.246*	0.195***	-0.140**	-0.110***	-0.138***
Use of heat tolerant maize seeds	0.383***	-0.241*	0.248***	-0.169*	-0.159***	-0.174***
Crop diversification	0.006***	-0.005***	-0.002	-0.004***	0.001	0.001

Sources: Estimation by FAO, using RALS 2012, 2015 and ARC2 data.
Note: * p<0.10; ** p<0.05; ***p<0.01: the level of statistical significance in results increases with the number of (*). The complete estimation results with the full range of control variables are available upon request.

Table APP 6 Estimated impact of CSA strategies under abnormally wet conditions

	Crop income	Crop income variability	Gross Income	Gross income variability	Poverty	Food insecurity
Minimum soil disturbance	-0.230***	0.018	-0.274***	0.040	0.119**	0.020
Residue retention	-0.091	0.021	-0.174*	0.128	0.077*	0.025
Legume rotation or intercrop	-0.031	-0.151***	-0.058	-0.081	-0.014	-0.040
Commercial horticulture	-0.002	-0.082*	0.049	-0.036	-0.003	-0.025
Agroforestry	-0.075	0.072	-0.006	0.117	0.056	-0.252***
Livestock crop integration	-0.026	-0.164*	-0.090	-0.328***	0.050	0.065
Livestock diversification	-0.000	-0.000	0.001	-0.001	-0.000	0.000
Delayed planting	-0.099***	-0.191**	-0.124***	-0.008	0.027	-0.021
Use of drought tolerant maize seeds	0.390***	-0.351**	0.190***	-0.136*	-0.092***	-0.150***
Use of heat tolerant maize seeds	0.435***	-0.426**	0.253***	-0.144	-0.155***	-0.201***
Crop diversification	0.006***	-0.004***	-0.002	-0.004***	0.001	0.001

Sources: Estimation by FAO, using RALS 2012, 2015 and ARC2 data.
Note: * p<0.10; ** p<0.05; ***p<0.01: the level of statistical significance in results increases with the number of (*). The complete estimation results with the full range of control variables are available upon request.

Appendix D: Cost-benefit Analyses

D.1 Methodological Approach

As discussed in Section 2.4, the CBA includes two assessments: (i) financial analysis to assess the financial viability of adopting CSA practices for households, and **(ii)** economic analysis to assess the impact of promoting CSA on the economy. This section expands on Section 2.4 to provide additional information.

Key assumptions of the financial analysis:

- All financial models conduct the analysis for 1 hectare of farmland.
- It is expected that yield increases as a consequence of adopting certain CSA practices such as minimum soil disturbance start, on average, in year 3.
- Production costs include cash input and family labor costs, such as the costs for purchase of seeds (improved varieties), chemical fertilizers (basal and top-dress), organic fertilizer (manure), herbicides, or expenses to hire animal draft power (ploughing or ripping with oxen). Financial prices are derived from the RALS data. Fertilizer prices are considered as full (financial) price and do not consider subsidies provided under FISP.
- Labor costs are estimated using rural market wage of 5.3 ZMK/person-day (which equals 6 hours per day) as a proxy, which was derived from the RALS dataset. This observed wage rate is lower than the minimum wage rate for general workers (6.2 ZMK/person-day) as established by the GoZ and effective since July 2012. This implies that the analysis presented here is estimated in a realistic manner, considering the real conditions of the job market in rural areas. Labor is valued in the same way, regardless if the laborer is a family member or a hired worker.
- No investment costs are considered for the crop models.
- For each model, the gross and net margins (the latter including labor cost as part of total production cost) are provided.

Key assumptions of the financial analysis:

The economic analysis is conducted over a 30-year period.

- Economic benefits are based on (i) the expected increased economic returns (private net benefits) of target households when adopting selected CSA practices as compared with conventional practices (i.e., the net incremental benefits); and (ii) public good benefits related to mitigating GHG emissions. Public good benefits are approximated by the net carbon balance, which is calculated using FAO's EX-ACT tool and valued at an annual shadow price of carbon.
- The net incremental benefits are valued at economic prices.
- Financial prices of tradable goods are converted into economic prices using a Standard Conversion Factor.16
- For some key traded goods, specific import/export parity prices at farm gate have been computed with reference to international border prices, applying conversion factors for each category of costs, and eliminating taxes and transfers.17
- A discount rate of 5 percent is applied following World Bank (2016).
- The economic cost of labor of 9.06 ZMW/person-day is used as a wage shadow rate, to factor in unemployment in rural areas.

- Investment cost for promoting CSA is assumed at US$41 (economic cost) per household per year. For a standard 6 years investment project, this results in US$260/household. The cost includes: Capacity building of extension service staff; demonstration trials and farmer field schools; provision of inputs (starter-packs) to farmers; research and development of improved/certified seeds; preparation of training material; sensitization and awareness meetings on CSA; and planning, monitoring, and evaluation of training activities.

D.2 Data Sources

As discussed in Section 2.4, data used include CSA-specific household data collected by the FAO, the RALS (see Appendix C.2 for a description), past investments in comparable programs, and the carbon accounting tool EX-ACT. This section expands on Section 2.4 in the main text.

- The CSA-specific survey was conducted by FAO within the project on Climate-smart agriculture in Malawi and Zambia (see http://www.fao.org/climatechange/epic/home/en/), funded by the European Commission. Data refer to the 2012-3 cropping season (Branca et al. 2015).
- While FAO and RALS data is available for all AEZs, the most detailed data is available for AEZ II. Specifically, for maize, detailed data for specific management practices is available. Minimum soil disturbance is the most frequently adopted practice and we use it as a proxy for other CSA practices.
- The assessment of public investment costs focuses on the period 2013-2018, is based on gray literature, and is mainly related to agriculture development projects in Zambia, integrated with ad hoc personal interviews of government institutions, independent research entities, international institutions, NGOs, and the private sector.
- FAO's EX-ACT tool, was developed primarily using the Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and Tier 1 emission coefficients, provides ex-ante measurements of the impact of agriculture (and forestry) projects and selected activities on GHG emissions and carbon sequestration. The tool provides a net carbon balance, as difference between gross emissions in a without and with project scenario, which is selected as an indicator of the mitigation potential of the project. EX-ACT measures carbon stocks and stock changes per unit of land, as well as methane (CH_4) and nitrous oxide (N_2O) emissions, expressing its results in tonnes of carbon dioxide equivalent per hectare (tCO_2e/ha) for the lifespan of a project and per year. The annual net carbon balance is valued at an annual shadow price of carbon (US$/$tCO_2e$) over the economic lifetime of the project (World Bank 2017b).
- The shadow price of carbon is in the range of US$40-80 per tCO_2e in 2020, rising to US$50-100 per tCO_2e by 2030 and to US$78-US$156 per tCO_2e by 2050. Thus, the price evolves at 2.25 percent each year. For the analysis we use the low value starting at US$40 per tCO_2e, and high value starting at US$80 tCO_2e as well as the high value, to account for the considerable uncertainty. The shadow price of carbon was developed by the High-Level Commission on Carbon Prices, led by Joseph Stiglitz and Nicholas Stern. The values are consistent with achieving the core objective of the Paris Agreement of keeping temperature rise below 2 degrees. For purposes of sensitivity analyses we also use potential carbon market price at US$5, US$11 and US$21 per tCO_2e.
- Data used to estimate the opportunity cost of capital was sourced from the World Bank and the Bank of Zambia. The financial discount rate is estimated at 12 percent, computed as an average between: (i) average deposit interest rate paid by commercial or similar banks in the country; (ii) lending interest rate; (iii) real interest rate; and (iv) long-term bonds rate (Table APP 7).

Table APP 7 Computation of discount rate to be used in the analysis

Indicator	Deposit interest rate	Lending interest rate	Real interest rate	Long-term bond rate	Average
Rate (%)	7.9	13.6	2.8	23	11.8

Source: Bank of Zambia, http://www.boz.zm/, last accessed August 2018

D.3 Selected Results

Results of the of the financial analysis are presented below. Table APP 8 and APP 9 provide crop yields for selected CSA practices and crops across AEZ. Table APP 10 provides annual net margins for conventional and CSA practices as well as the incremental net revenues.

Table APP 8 Crop yields by AEZ and farming practices (Kg/ha)

Crop	AEZ I	AEZ IIa	AEZ IIb	AEZ III	AEZ I	AEZ IIa	AEZ IIb	AEZ III	AEZ I	AEZ IIa	AEZ IIb	AEZ III
	Conventional				CSA/MSD				% difference			
Beans	586	497	601	539	821	696	842	680	40	40	40	26
Cassava	1,912	5,214	2,575	6,993	2,231	6,083	3,004	8,100	17	17	17	16
Cotton	1,037	992	999	n/a	n/a	684	n/a	n/a	n/a	-31	n/a	n/a
Cowpeas	490	616	383	400	930	1,170	728	700	90	90	90	75
Groundnuts	356	430	852	730	509	615	1,219	900	43	43	43	23
Maize	1,654	1,933	1,217	3,575	1,930	2,475	1,420	2,200	17	28	17	-38
Rice	1,891	1,771	1,510	1,386	3,045	2,852	2,431	2,231	61	61	61	61
Soybeans	1,820	894	196	831	2,639	1,296	285	1,204	45	45	45	45

Source: FAO-CSA survey (season 2012-3) and RALS 2015 datasets, personal interviews and focus group discussions
Note: n/a indicates that information was not available. MSD stands for minimum soil disturbance. Values for MSD are used as a proxy for CSA practices.

Table APP 9 Crop yields for maize for alternative MSD systems in AEZ IIa (Kg/ha)

Crop	Conventional		CSA				
	Conventional hand hoe/ ridging	Ploughing with oxen	Planting basins/ potholes	Ripping with oxen	MSD and agroforestry	MSD and legume rotation	MSD and residue retention
Maize	1,933	1,618	2,139	2,229	2,644	2,893	2,134

Source: FAO-CSA survey (season 2012-3) and RALS 2015 datasets, personal interviews and focus group discussions
Note: MSD stands for minimum soil disturbance.

Table APP 10 Annual net margins and incremental benefits for each crop and AEZ in US$/ha

Crop	AEZ I	AEZ IIa	AEZ IIb	AEZ III	AEZ I	AEZ IIa	AEZ IIb	AEZ III	AEZ I	AEZ IIa	AEZ IIb	AEZ III
	Net margins—conventional practices				Net margins—CSA/MSD				Net incremental benefits			
Beans	-71	-100	-67	-87	-62	-101	-65	-110	10	0	2	-24
Cassava	24	392	98	590	13	443	89	664	-11	51	-9	74
Cotton	39	28	30			-21			0	-49	0	0
Cowpeas	23	39	10	12	88	94	96	68	65	55	87	56
Groundnuts	31	60	224	177	78	133	357	240	47	73	132	63
Maize	21	48	-22	132	51	86	1	53	30	38	23	-79
Rice	242	218	165	140	441	404	305	271	199	186	140	131
Soybeans	108	-11	-100	-19	238	90	-39	78	130	101	61	97

Source: FAO calculated based FAO-CSA survey (season 2012-3) and RALS 2015
Note: For maize in AEZ IIa, the net margins and net incremental benefits present the average across farming practices CSA/MSD practices which are presented in Table APP 9.

Appendix E: GLOBIOM

E.1 Methodological Approach

As discussed in Section 2.5, GLOBIOM is an integrated modeling approach that allows for joint analysis of the agriculture and forestry, and bioenergy sectors. This section expands on the overview provided in Section 2.5 and provides more detail about the following aspects of the GLOBIOM model: (i) The GLOBIOM analytical process; (ii) Description of policy scenarios and CSA-adoption scenarios; (iii) Sensitivity analysis: Climate change uncertainty; (iv) Sensitivity analysis: Shared Socioeconomic Pathways.

(i) The GLOBIOM analytical process

Drivers of agricultural development in Zambia include both local and global factors, thus a global-to-local modelling approach is adopted. At the local level, national policies, population growth and economic growth are key drivers, while at the global level, climate change and international trade are important factors. The interplay between these two sets of drivers will eventually determine the future development trajectory of agriculture in Zambia. For this analysis a global-to-local modelling approach is adopted which incorporates both the global and local drivers of agricultural growth. To capture the high level of uncertainty related to the future development of these drivers, a scenario framework is applied that considers uncertainties associated with climate change such as precipitation and temperature changes, and the possible trajectories of socioeconomic drivers of agricultural growth such as population growth, economic development and technical change. The methodology is similar to the one used in recent global impact assessments of climate change (O'Neill et al. 2017).

GLOBIOM's analytical process captures the multiple interrelationships between the different systems involved in provision of agricultural and forestry products, for example, population dynamics, ecosystems, technology, and climate (Figure APP 1). This allows for quantifying the impact of global and national developments on the agricultural sector in Zambia. GLOBIOM draws on results of following models to simulate future agriculutral development:

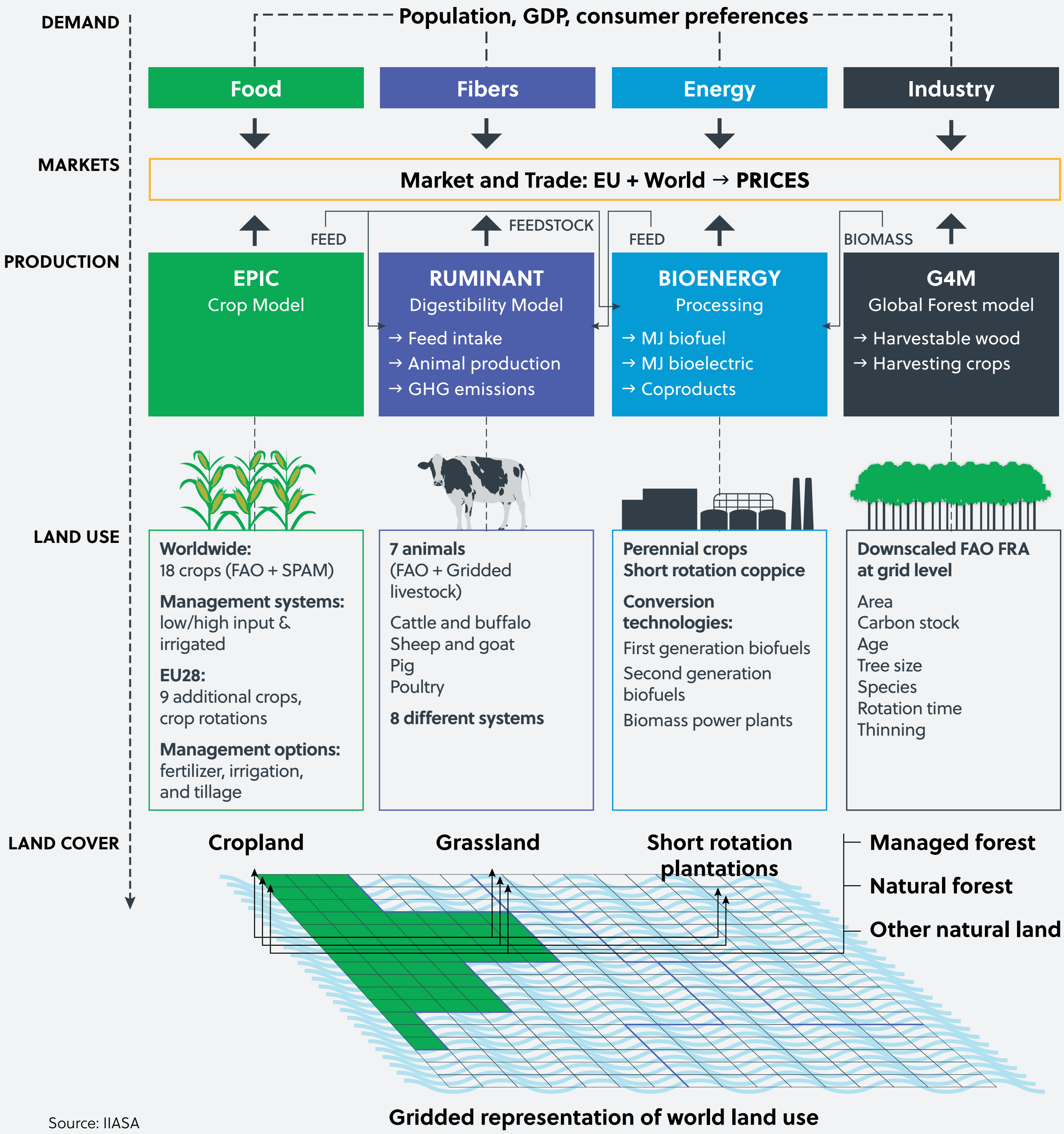
- The biophysical process simulation model **Environmental Policy Integrated Climate** (EPIC) to model agronomic and environmental processes;
- **RUMINANT** to capture livestock activities; and
- **BIOENERGY** and **G4M** to capture energy demand and forestry management, respectively.

The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, subject to resource, technological and policy constraints (McCarl and Spreen 1980). Trade flows are balanced out between specific geographical regions based on the spatial equilibrium approach (Schneider et al. 2007; Takayama and Judge 1971). Trade is based purely on cost competitiveness as goods are assumed to be homogeneous. This allows tracing of bilateral trade flows between individual regions.

Furthermore, the following model specifications stand out:

- The ***supply side*** of the model is based on a bottom-up approach considering: land cover, land use, and management systems and related production and markets. Agricultural and forest productivity stems from crop models and forest models and is modeled at the level of grid cells of 5x5 to 30x30 arc-minutes. For instance, globally gridded simulated crop yields and resource requirements

Figure APP 1 Overview of GLOBIOM



Source: IIASA

(fertilizer, water, costs) are based on the EPIC model described above (see Figure APP 11). Also crop models Lund-Potsdam-Jena managed Land model (LPJmL) is used and the forestry model G4M.

- The *level of production* in a given area is determined by the agricultural or forestry productivity in that area (dependent on suitability and management), by market prices (reflecting the level of demand), and by the conditions and cost associated to conversion of the land, to expansion of the production and, when relevant, to international market access. Production is calibrated to match FAO statistics at the country level (FAOSTAT 2017). GLOBIOM captures production systems and land use in its base year (2000), using available historical data from SPAM (You and Wood 2006).

- The ***demand side*** is modeled at the regional level using 30 economic regions that consist of single countries or bundles of countries based on the food balance sheets developed by the FAO (FAOSTAT 2017; Alexandratos et al. 2006). For this version of the model, Zambia has been taken out of the region "Southern Africa" to further develop.
- ***Trade flows*** are balanced out between different specific geographical regions based on the spatial equilibrium approach (Schneider et al. 2007; Takayama and Judge 1971). Trade is based purely on cost competitiveness, as goods are assumed to be homogeneous.
- GLOBIOM uses a ***recursive dynamic approach*** combined with exogenous trends on population and economic growth to create future projections for key indicators, such as crop and livestock production and prices, land use change, greenhouse gas emissions and calorie availability.
- GLOBIOM accounts for ***10 sources of GHG emissions***, including crop cultivation-related N_2O emissions from fertilizer use, CH_4 from rice cultivation, livestock-related CH_4 emissions, CH_4 and N_2O emissions from manure management, N_2O from manure applied on pasture, and above- and below-ground biomass CO_2 emissions from biomass removal after converting forest and natural land to cropland.
- ***Model adjustments for the Zambia*** context are described in Section 2.5. The Zambia region in GLOBIOM is modeled and optimized at 32 land units that consider differences in agro-ecological zones (AEZ) for a total of 57 land units. Structural model developments from Frank et al. (2018) were used to further develop the mitigation options for Zambia; assumptions of yield and mitigation potential of some of the mitigation technology options were further refined from Beach et al. (2015), and based on the stakeholder validation workshop held in April 2018.

(ii) Description of BAU scenario and CSA adoption scenarios

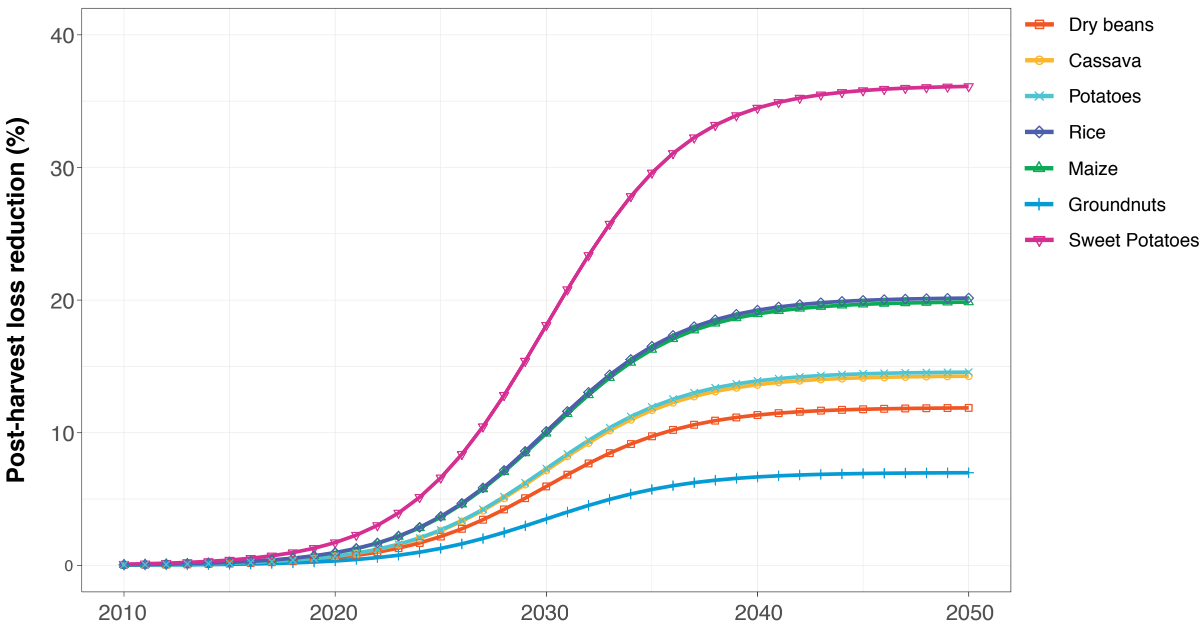
In order to evaluate the impact of CSA technologies on measurable goals, several assumptions about CSA technologies are made. The business as usual (BAU) scenario assumes that key trends from recent decades will continue in the future, including the application of conventional management practices on a large share of cropland area. As such, it presents the baseline to which other scenarios can be compared and is based on RALS data. Table APP 12 summarizes assumptions for modelling CSA. Three factors will determine CSA's impact on agricultural and environmental indicators: (1) crop yield and GHG parameters, which reflects the direct impact of the CSA strategy per unit of land; (2) adoption rate, which reflects the size of the area on which the CSA strategy is used and (3) number of crops on which the CSA strategy is applied.

Table APP 11 Model assumptions for CSA technologies

CSA technology	2010 adoption rate (%) (BAU)	Crops included	Productivity impact (% increase from BAU)	GHG impact per hectare (% from BAU)	Adoption rate in 2050 (%) (CSA)
Minimum soil disturbance	8.9% of maize area	Beans, cassava, chickpeas, cotton, groundnuts, rice, soya	Beans (40%), cassava (17%), chickpeas (90%), cotton (60%), groundnuts (43%), rice (61%), soya (45%)	min -8%	50
Residue retention	56.6% of crop area	Maize, cotton	Maize (24%), cotton (3%)	max +27%	80
Conservation agriculture	0.3% of crop area	Maize, cotton	Maize (79%), cotton (42%)	-0.74%	30
Agroforestry	5% of crop area	Cotton, groundnut, maize, and soya	Cotton (18%), groundnut (18%), maize (63%), and soya (18%)	no GHG mitigation[a]	25
Drought-tolerant maize	23% of maize area	Maize	Mitigates negative impacts from climate change	no GHG mitigation	70
Post-harvest losses	Almost 0% reduction reached	All crops	Figure APP 2[c]	no GHG mitigation	Not applicable
Crop diversification	Maize holdings of the Food Reserve Agency (FRA) in Zambia is about 500,000 MT	Maize, Soybean, Groundnut	Maize: production cost return to the pre-FSIP levels[b] Soybean: 50% reduction in production costs Groundnut: 50% reduction in production costs	+7%	Maize holdings are reduced and would not exceed 300,000 MT after 2020

Source: IIASA using information from Thierfelder et al. (2013); Frank et al. (2018); Shitumbanuma (2012); Haggblade and Tembo (2003); Harman and Chapoto (2017) and stakeholder consultation
Notes: (a) no GHG mitigation impact refers to 10 sources of GHG emissions (see above) which can be modelled with GLOBIOM; however, soil carbon sequestration or biomass growth or indirect effects through reduction of land use change or land under cultivation are not considered. (b) Traditionally, FISP reduces production cost for maize; to model crop diversification, it is assumed that production costs of maize return to pre-FSIP levels and costs for soybeans and groundnuts are decreased by 50%. (c) Figure APP 2 shows the level of post-harvest loss reduction, indicating increases in total production, which will results in increased production per hectare. These values are not specific for Zambia. They have been observed neighboring countries and serve as an approximation.

Figure APP 2 Post-harvest loss diffusion scenario: 2010-2050



Source: IIASA, using information from Affognon et al. (2015)

(iii) Sensitivity analysis: Climate change uncertainty

To analyze the impact of climate change, sensitivity analyses are conducted to account for the high level of uncertainty associated with the impact of climate change on crop yields. The outputs of five general circulation models (GCMs) are combined with two crop models, EPIC and LPJmL, to obtain a bandwidth of the yield shock that is caused by climate change in comparison to a no climate change scenario. The GCMs are combined with different levels of atmospheric CO_2 concentrations as prescribed by the representative concentration pathways (RCP) to show the impact of climate change on global changes in temperature and precipitation. We use RCP 8.5, which is the most extreme climate scenario (Riahi et al. 2011), for the period up to 2050. The GCMs include:

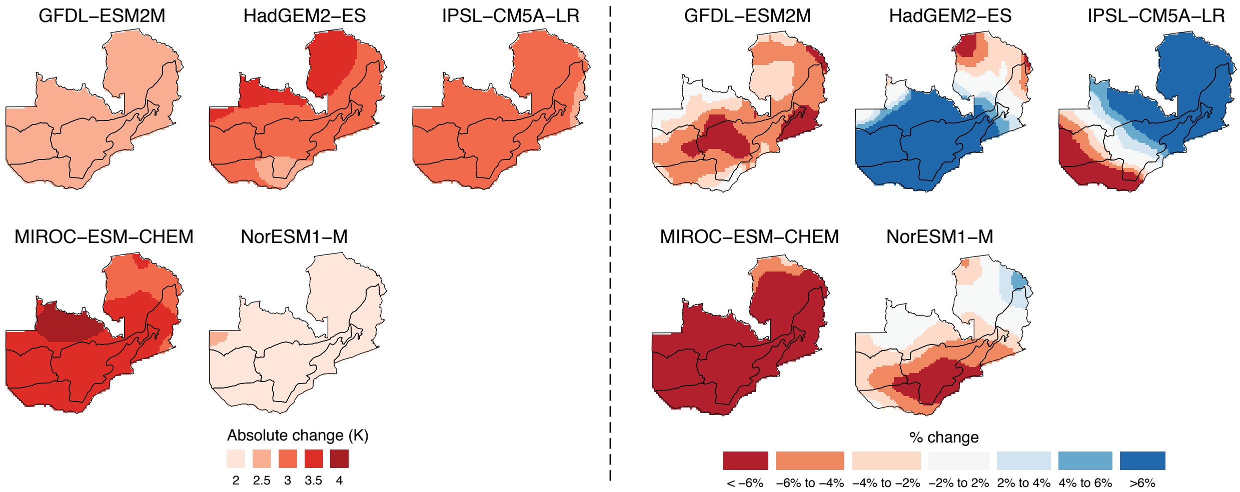
- HadGEM2-ES—Hadley Global Environment Model 2—Earth System
- IPSL-CM5A-LR—Earth System Model for the 5th IPCC report (Low Resolution)
- GFDL-ESM2M—Geophysical Fluid Dynamics Laboratory Earth System Model
- MIROC-ESM-CHEM—Model for Interdisciplinary Research on Climate (with atmospheric chemistry component)
- NorESM1-M—Norwegian Earth System Model

The effect of CO_2-fertilization is debated. The scientific community has yet to reach an agreement on whether the potential benefits from increases in CO_2 can be taken up and used by crops, especially if temperature and precipitation are expected to reduce crop yields. For this reason, a climate change scenario variant using the HadGEM2-ES model is included that assumes both with and without CO_2 fertilization. Taken together crop yield results can show the potential range of the biophysical and economic impacts on crop yields from climate change. The simulated yield shocks only account for the effect of long-run changes in precipitation and temperature, but do not capture extreme climate effects or the potential increase in pests and diseases that affect plant growth.

Projections of key productivity drivers vary significantly across models. Figure APP 3 depicts the change in mean annual temperature and mean annual precipitation between 1980/2000 and 2040/2060 in Zambia for all five GCMs. The figure demonstrates the high uncertainty in projecting climate change. The MIROC-ESM-CHEM and HadGEM2-ES climate scenarios project the most extreme increase in temperature of around 3.5 degrees Celsius, while the other three scenarios project that temperature will change by around 2-3 degrees Celsius. The MIROC-ESM-CHEM also projects the driest scenario, with a decrease in precipitation of more than 6 percent across Zambia, apart from the far north. In addition, GFDL-ESM2M and NorESM1-M project a decrease in rainfall but with variation across Zambia. In contrast, HadGEM2-ES and IPSL-CM5A-LR predict an increase in precipitation of more than 6 percent by 2040-2060, although the GCMs do not agree where in Zambia this will take place.

As expected, different models yield highly diverging results across crops and regions. As discussed in Section 5.1 and shown in Figure 5.1, simulated crop yield changes dramatically across climate models for almost all crops in Zambia. It is important to take spatial effects into account, which is shown in Section 5.1, Figure 5.2. Although maize is grown throughout all regions in Zambia, most is produced in the Eastern Province, where yield loss is expected to be between 5 and 25 percent.

Figure APP 3 Change of temperature (left) and precipitation (right) using five different GCMs with RCP 8.5 (1980/2000-2040/2060)



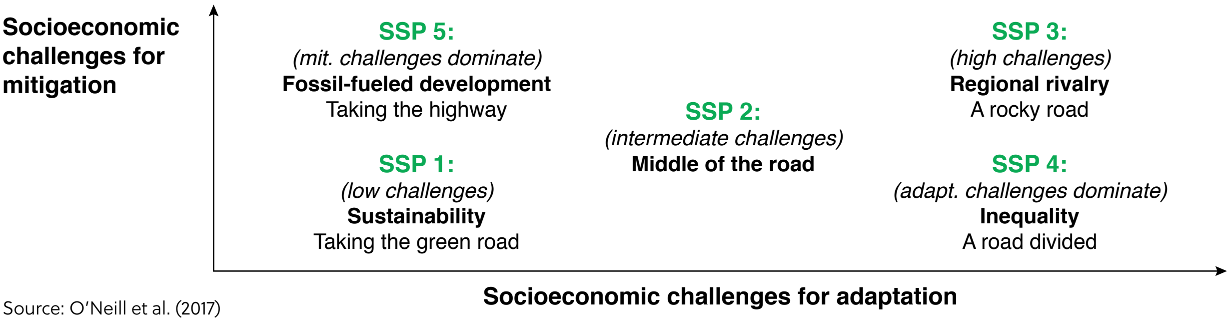
Source: IIASA using coupled Model Intercomparison Project Phase 5 (https://cmip.llnl.gov/cmip5)
Note: (a) Difference in bias-corrected, average surface air temperature (absolute change K) over land and (b) relative difference in average annual rainfall (in percent) between 2040–2060 and 1980–2000 under RCP8.5 in the five climate models used in the ISI-MIP. To increase the visualization, the original 0.5° × 0.5° resolution has been smoothed to 5 x 5 arcmin.

(iv) Sensitivity analysis: Shared Socioeconomic Pathways (SSPs) and results

To model a business-as-usual (BAU) scenario for Zambia, we use the Shared Socio-economic Pathways (SSPs), which were developed as a backbone for climate change related assessments by a large consortium of researchers (Kriegler et al. 2012; van Vuuren et al. 2017; O'Neill et al. 2017). These scenarios provide a global context and/or template for scenarios at lower geographical levels and can be used to guide regional, national or sub-national planning (O'Neill et al. 2014). Sub-global scenarios can complement the SSPs with more regional contextualization of assumptions and results, even when using scenarios in the global setting.

The SSPs are a set of plausible and alternative assumptions that describe potential future socio-economic development in the absence of climate policies or climate change. They consist of two elements: a narrative storyline and a quantification of key drivers. The scenarios are based on two dimensions of challenges, namely mitigation and adaptation (O'Neill et al. 2014) (Figure APP 4). The combination of challenges from which scenarios emerged were then constructed by identifying the drivers of the challenge outcomes such as population and urbanization (KC and Lutz 2017) and economic growth (Dellink et al. 2017) and building a rich narrative of each pathway using the quantitative and semi-quantitative drivers (O'Neill et al. 2017). Projections have global coverage and are provided at country level, including Zambia.

Figure APP 4 Shared Socio-economic Pathways scenario framework



Source: O'Neill et al. (2017)

For this business as usual scenario, the projections for SSP2: Middle of the Road (Fricko et al. 2017) is adopted. The narrative of SSP2 can be summarized as follows:
"The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries." (O'Neill et al. 2017).

The SSPs do not include projections for crop yields and livestock feed convergence efficiency, which are essential to model future agricultural productivity growth. Yield projections are used from Herrero et al. (2014) and Fricko et al. (2017) and are estimated using the historical relationship between GDP growth and crop yield increase. It is assumed that that these projections represent intrinsic productivity rates and reflect the increase in yield because of advances in knowledge and new technologies. Livestock feed conversion efficiencies are used from Herrero et al. (2014) and Fricko et al. (2017). However, there is less information available on future trajectories of livestock feed conversion efficiencies (the amount of feed required per livestock category such as dairy, ruminant meat, pork, and poultry) and how it could be affected climate change (e.g., Bouwman et al. 2005; Wirsenius et al. 2010).

To investigate the uncertainties in the socioeconomic projections, the results of two additional SSP scenarios are modeled and compared: SSP1: Sustainability—Taking the green road and SSP3: Regional rivalry—A rocky road, which represent two opposing types of scenarios" to represent the bandwidth of the socioeconomic spectrum, including uncertainties related to both external (global markets and the political situation) and internal conditions *"SSP1 with its central features of commitment to achieving development goals, increasing environmental awareness in societies around the world, and a gradual move toward less resource-intensive lifestyles, constitutes a break with recent history in which emerging economies have followed the resource-intensive development model of industrialized countries. To some extent, elements of this scenario can already be found in the proliferation of 'green growth' and 'green economy' strategies in industrialized and developing countries." (O'Neill et al. 2017). And SSP3 "with its theme of international fragmentation and a world characterized by regional rivalry can already be seen in some of the current regional rivalries and conflicts, but contrasts with globalization trends in other areas. It is based on the assumption that these globalization trends can be reversed by a number of events"* (O'Neill et al. 2017).

Figures APP 5–APP 8 show crop yield projections, production, land use change, and emissions from synthetic fertilizers for the BAU scenario SSP2 as well as for SSP1 and SSP3. The figures show that for all indicators, the SSP1 scenario is more "positive" than the BAU, while SSP3 shows more "negative" results. As a consequence of high GDP growth in the SSP1 scenario, technological change is faster, resulting in higher yields for all crops. The reverse is the case for SSP3. Due to relatively low population growth, which in turn results in low demand, total production is projected to be the lowest in SSP1. The pattern for SSP3 resembles that of SSP2. Cropland expansion is also expected to be the lowest in SSP1 because of the higher yields and lower demand. Again, a reverse pattern can be observed for SSP3. Interestingly, the expansion of cropland under the SSP3 scenario is so large that it will overshoot the maximum as set by the vision target. For emissions, SSP1 results in the lowest amount of emissions but this is not close to the level needed to reach targets as set by the NDC (which are in comparison with the BAU scenario).

Figure APP 5 Crop yield under different socioeconomic scenarios

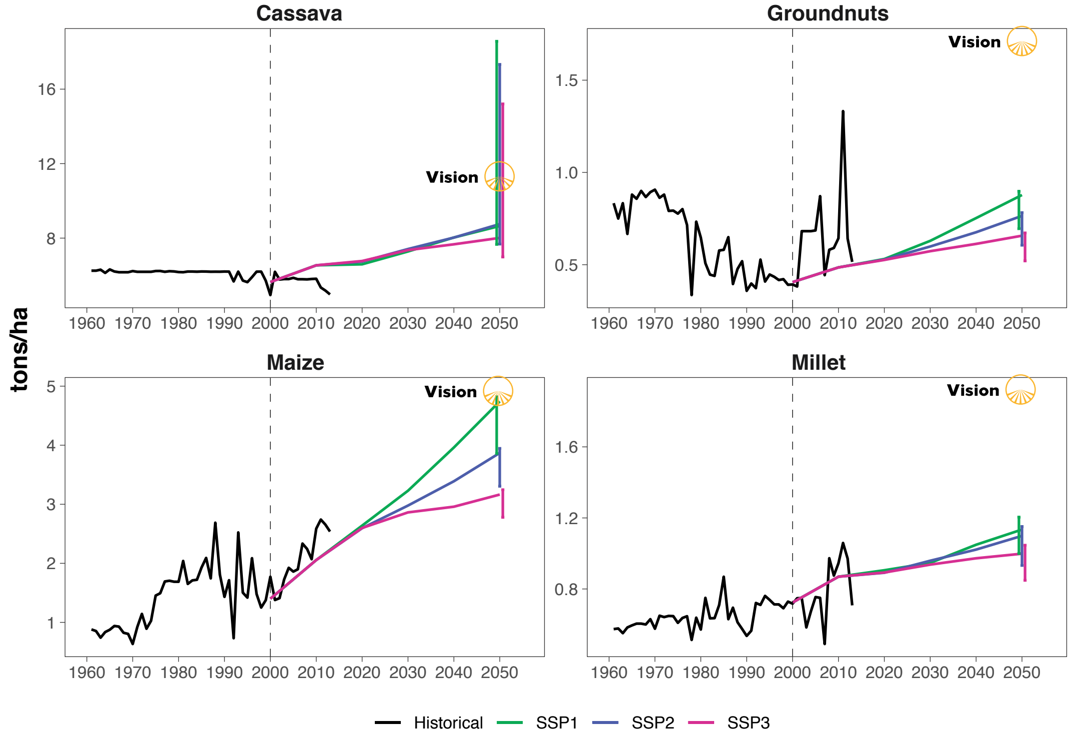


Figure APP 6 Land use change under different socioeconomic scenarios

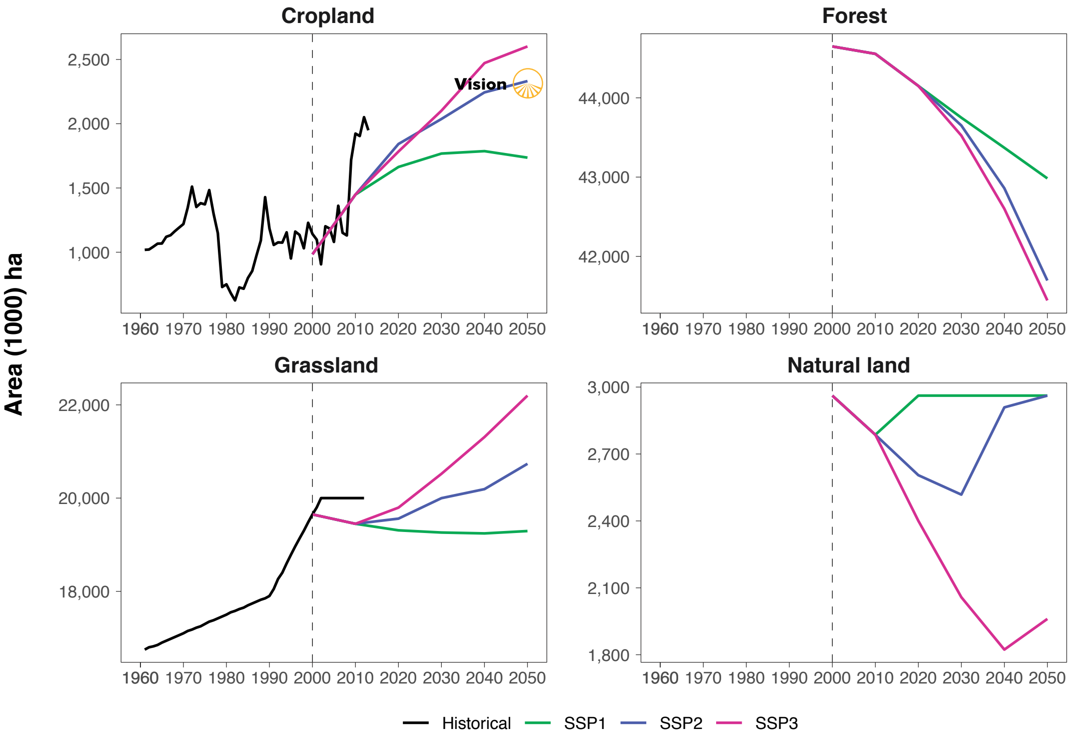


Figure APP 7 Crop production under different socioeconomic scenarios

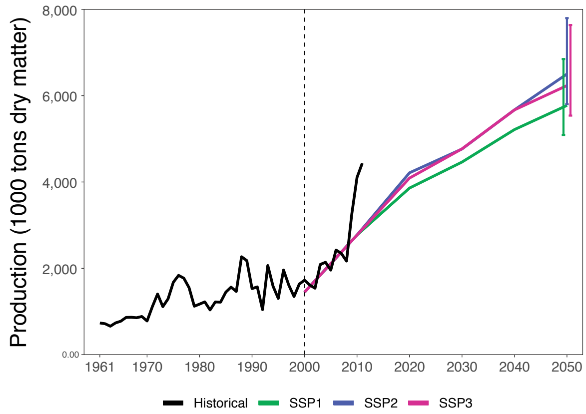
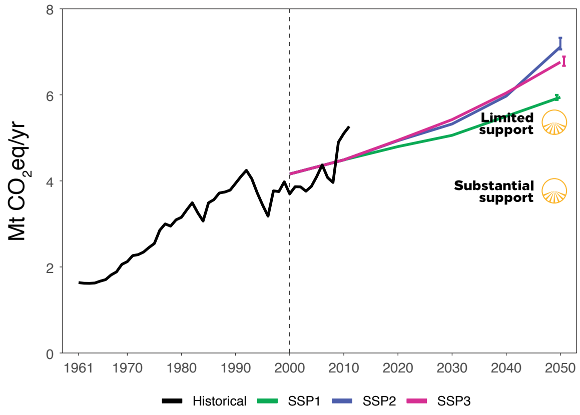


Figure APP 8 Emissions from synthetic fertilizers under different socioeconomic scenarios



Sources (Figures APP 5–8): Historical values are from FAOSTAT; the GLOBIOM model provides projections from 2000-2050; "Vision" target represents agriculture sector goals in 2050 which were agreed on during the stakeholder workshop and/or policy documents.

E.2 Detailed Results: Output Tables

In this section, more detailed outputs of the GLOBIOM model are presented. Figure APP 9 provides a spatial representation of land use patterns, which are described in Section 5.4. Table APP 12–Table APP 16 provide summaries of GLOBIOM outputs as they pertain to production, land use, emissions, yield, and net trade. In each case, the 2010 values are contrasted with 2050 targets (as presented in Section 2, Table 2.2); we present the 2050 projections for the business as usual scenario, without and with climate change; the 2050 projections for average CSA adoption, without and with climate change. We calculate the average across CSA practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. We present the maximum, average, and minimum values calculated across all 5 GCMs and 2 crop models, to show the range of projected impacts. In the last columns, the change of CSA compared to the application of conventional practices in 2050 in a without climate change and with climate change scenarios are shown; as well as compared to the agriculture sector targets. For all values, SSP2 was used as a default configuration.

Figure APP 9 Projected land use changes between 2000 and 2050, in percent

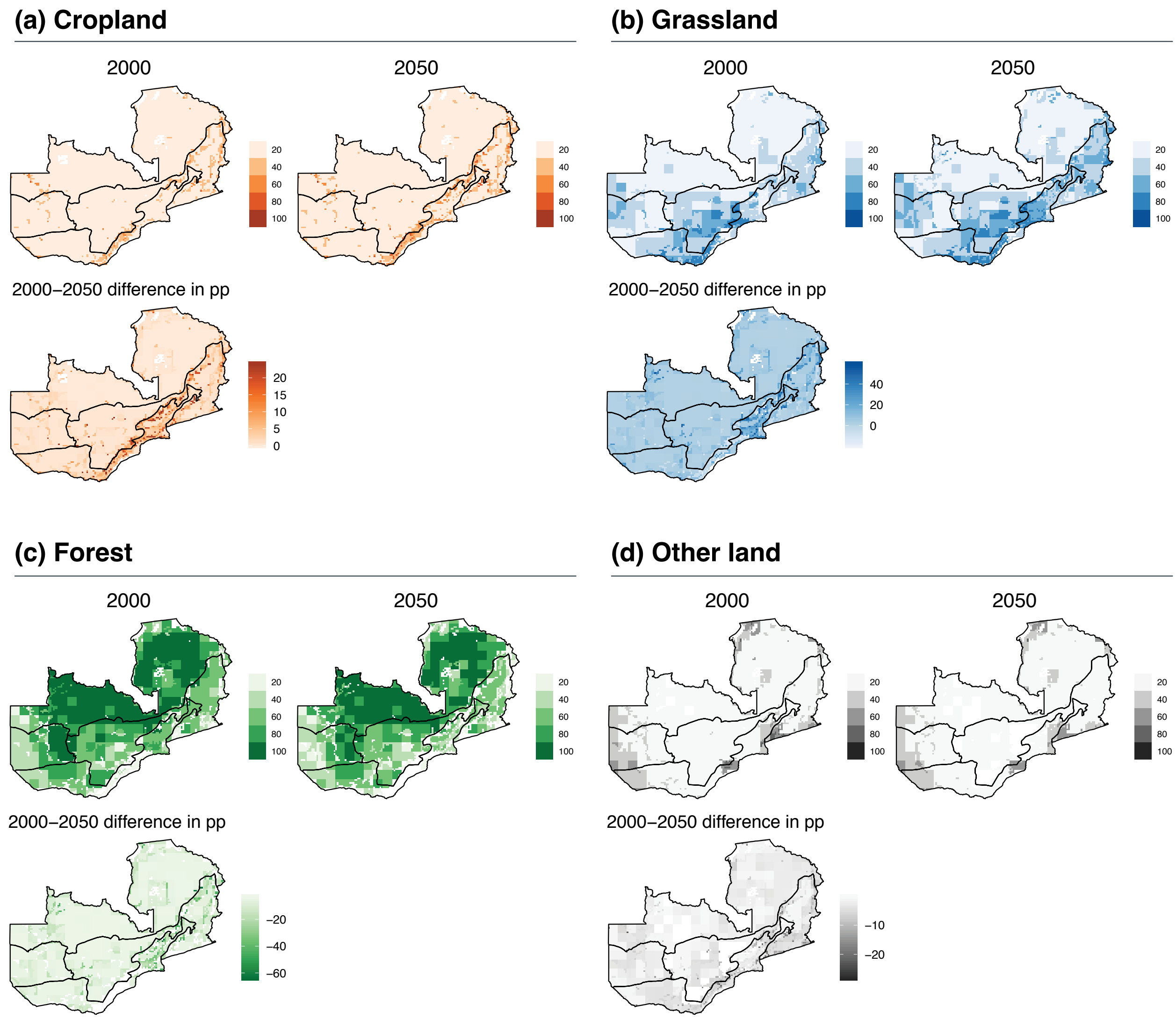


Table APP 12 Land use in 1000 hectares, by land use category

			2050 Conventional practices				2050 CSA				CSA vs. conventional practices in 2050		CSA vs. target in 2050	
			No Climate Change	Climate Change			No Climate Change	Climate Change			No Climate Change	Climate Change	No Climate Change	Climate Change
Land Types	2010 Target	2050 Target		Min.	Avg.	Max.		Min.	Avg.	Max.	% change across averages		% change across averages	
Total	**68,263**	**N/A**	**67,693**	**64,150**	**67,714**	**70,996**	**67,764**	**66,684**	**67,849**	**69,032**	**0.10%**	**0.20%**	**N/A**	**N/A**
Forest	44,555	N/A	42,041	41,371	42,026	42,989	41,660	41,460	41,650	41,756	-0.91%	-0.89%	N/A	N/A
Grassland	19,449	N/A	20,742	19,122	20,808	22,378	20,678	20,101	20,819	21,160	-0.31%	0.06%	N/A	N/A
Nat. land	2,786	N/A	2,628	1,888	2,629	2,962	2,962	2,962	2,962	2,962	12.70%	12.66%	N/A	N/A
Cropland	1,473	2,373	2,281	1,769	2,252	2,667	2,464	2,161	2,418	3,154	8.01%	7.38%	4%	2%

Source: World Bank, based on GLOBIOM model outputs; values for 2010 are based on FAOSTAT data.
Note: CSA refers to average values of following practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. Colors indicate the relative change of land use as a result of CSA; dark green indicates the most positive change (across land types), dark red the least positive change.

Table APP 13 Production in 1000 tons, by crop

Crop	2010 Target	2050 Target	2050 Conventional practices				2050 CSA				CSA vs. conventional practices in 2050		CSA vs. target in 2050	
			No Climate Change	Climate Change			No Climate Change	Climate Change			No Climate Change	Climate Change	No Climate Change	Climate Change
				Min.	Avg.	Max.		Min.	Avg.	Max.	% change across averages		% change across averages	
Total	**2,788**	**5,576**	**6,548**	**5,700**	**6,870**	**7,998**	**6,933**	**5,685**	**7,313**	**10,085**	**6%**	**6%**	**24%**	**31%**
Maize	1,281	2,562	4,051.56	3,907.40	4,024.25	4,073.06	4,277.15	3,912.99	4,268.29	4,610.60	6%	6%	67%	67%
Sugarcane	758	1,517	1,124.72	520.95	1,465.46	2,413.55	1,156.86	520.95	1,544.02	3,173.92	3%	5%	-24%	2%
Cassava	259	519	624.89	613.74	640.69	669.02	642.99	608.33	658.96	757.01	3%	3%	24%	27%
Wheat	123	246	18.37	12.93	23.51	50.50	18.60	0.14	21.01	50.49	1%	-11%	-92%	-91%
Groundnut	84	169	205.59	168.47	188.41	210.38	272.35	168.47	249.71	631.60	32%	33%	61%	48%
Soya	83	165	59.06	58.23	61.93	64.20	82.83	58.23	87.26	232.04	40%	41%	-50%	-47%
Millet	44	89	188.64	160.02	176.83	197.69	194.00	160.13	181.89	237.28	3%	3%	118%	105%
Cotton	42	85	72.10	66.46	77.82	87.89	76.90	66.45	82.97	105.76	7%	7%	-9%	-2%
Sweet potato	37	75	36.39	31.17	36.75	41.45	38.26	31.17	38.51	55.27	5%	5%	-49%	-49%
Rice	33	67	37.07	35.65	37.92	39.98	39.25	35.54	40.14	48.24	6%	6%	-41%	-40%
Sorghum	18	36	74.77	76.76	80.05	86.02	77.37	74.22	82.57	106.39	3%	3%	112%	127%
Sunflower	14	27	46.76	46.03	49.22	51.62	47.57	46.03	50.06	57.86	2%	2%	73%	82%
Barley	7	15	0.15	0.15	1.77	4.17	1.09	0.15	2.26	8.89	646%	27%	-93%	-84%
Potato	3	6	8.00	1.78	4.98	8.48	8.18	1.78	5.59	9.86	2%	12%	47%	0%

Source: World Bank, based on GLOBIOM model outputs; values for 2010 are based on FAOSTAT data.
Note: CSA refers to average values of following practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. Colors indicate the relative change of production as a result of CSA; dark green indicates the most positive change, dark red the least positive change.

Table APP 14 Emissions in $MtCO_2e$/yr, by emission source

Crop	2010 Target	2050 Target (limited support)	2050 Target (sub-stantial support)	2050 Conventional practices				2050 CSA				CSA vs. conventional practices in 2050		CSA vs. target in 2050	
				No Climate Change	Climate Change			No Climate Change	Climate Change			No Climate Change	Climate Change	Limited support	Sub-stantial support
					Min.	Avg.	Max.		Min.	Avg.	Max.	% change across averages		% change across averages	
Total LULUCF	**6.4**	**28.5**	**19.3**	**37.6**	**35.5**	**38.0**	**39.9**	**37.5**	**35.1**	**38.2**	**41.8**	**-0.32%**	**0.50%**	**25%**	**50%**
Deforestation	1.8	N/A	N/A	23.9	22.1	23.3	23.9	23.8	21.9	23.3	23.9	-0.07%	-0.18%	N/A	N/A
Other land use change	1.5	N/A	N/A	12.7	12.7	13.7	14.9	12.7	12.7	13.9	15.9	-0.28%	15.59%	N/A	N/A
Sum of land use change	3.2	N/A	N/A	1.0	0.7	1.0	1.1	1.0	0.5	1.1	2.1	-6.58%	109.59%	N/A	N/A
Total agriculture	**4.5**	**5.3**	**3.8**	**7.1**	**7.0**	**7.2**	**7.4**	**7.2**	**6.9**	**7.2**	**8.0**	**0.91%**	**0.91%**	**36%**	**92%**
Enteric fermentation	2.4	N/A	N/A	3.6	3.6	3.6	3.7	3.6	3.6	3.7	3.8	0.21%	0.30%	N/A	N/A
Manure left on Pasture	1.5	N/A	N/A	0.1	2.1	2.1	2.2	0.1	2.1	2.1	2.2	0.16%	0.00%	N/A	N/A
Synthetic Fertilizers	0.3	N/A	N/A	2.1	0.9	0.9	1.0	2.1	0.8	1.0	1.4	0.17%	3.58%	N/A	N/A
Manure Mgmt. CH_4	0.1	N/A	N/A	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.19%	-7.40%	N/A	N/A
Manure applied to Soils	0.1	N/A	N/A	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.4	0.22%	21.88%	N/A	N/A
Manure Management N_20	0.1	N/A	N/A	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.00%	1.15%	N/A	N/A
Rice Cultivation	0.1	N/A	N/A	0.9	0.1	0.1	0.1	1.0	0.1	0.1	0.1	5.59%	0.01%	N/A	N/A

Source: World Bank, based on GLOBIOM model outputs; values for 2010 are based on FAOSTAT data.
Note: CSA refers to average values of following practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. Colors indicate the relative change of emissions as a result of CSA; dark green indicates the most positive change, dark red the least positive change.

Table APP 15 Yield in tons per hectare per year, by crop

Crop (net trade)	2010	2050 Target	2050 Conventional practices				2050 CSA				CSA vs. conventional practices in 2050		CSA vs. target in 2050	
			No Climate Change	Climate Change			No Climate Change	Climate Change			No Climate Change	Climate Change	No Climate Change	Climate Change
				Min.	Avg.	Max.		Min.	Avg.	Max.	% change across averages		% change across averages	
Total	**10**	**20**	**8.8**					**14**	**15**	**17**				
Cassava	6.5	11.3	8.75	N/A	N/A	N/A	8.75	8.67	8.97	9.97	N/A	N/A	N/A	-21%
Maize	2.1	4.9	3.87	N/A	N/A	N/A	3.87	3.78	4.03	4.75	N/A	N/A	N/A	-18%
Millet	0.9	1.9	1.10	N/A	N/A	N/A	1.10	0.96	1.10	1.32	N/A	N/A	N/A	-43%
Groundnuts	0.5	1.7	0.76	N/A	N/A	N/A	0.76	0.75	0.80	0.89	N/A	N/A	N/A	-53%

Source: World Bank, based on GLOBIOM model outputs; values for 2010 are based on FAOSTAT data.
Note: CSA refers to average values of following practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. Colors indicate the relative change of yield as a result of CSA; dark green indicates the most positive change, dark red the least positive change.

Table APP 16 Net trade in 1000 tons

Crop (net trade)	2010	2050 Target	2050 Conventional practices				2050 CSA				CSA vs. conventional practices in 2050		CSA vs. target in 2050	
			No Climate Change	Climate Change			No Climate Change	Climate Change			No Climate Change	Climate Change	No Climate Change	Climate Change
				Min.	Avg.	Max.		Min.	Avg.	Max.	% change across averages		% change across averages	
Total	**498**	**996**	**-1,066**	**(1,835)**	**(1,034)**	**(402)**	**(831)**	**(2,053)**	**(747)**	**2,410**	**-22%**	**-28%**	**-183%**	**-175%**
Sugarcane	468	N/A	(0.99)	(383.31)	88.56	440.85	5.83	(468.91)	184.01	2,181.21	-689%	108%	N/A	N/A
Cassava	54	N/A	25.45	25.14	87.53	163.26	75.10	(0.16)	135.58	404.22	195%	55%	N/A	N/A
Cotton	37	N/A	49.40	34.61	50.90	68.59	53.36	13.76	53.29	88.22	8%	5%	N/A	N/A
Maize	28	N/A	152.19	36.96	103.33	152.07	223.73	35.05	169.09	314.78	47%	64%	N/A	N/A
Sweet potatoes	14	N/A	(171.37)	(203.34)	(178.33)	(151.94)	(162.85)	(203.34)	(169.82)	(96.75)	-5%	-5%	N/A	N/A
Millet	2	N/A	81.75	27.70	60.46	92.62	85.82	17.04	63.77	137.05	5%	5%	N/A	N/A
Bovine meat	-1	N/A	9.72	6.64	8.85	9.98	10.02	4.22	8.70	10.09	3%	-2%	N/A	N/A
Soybeans	-4	N/A	(259.66)	(260.59)	(256.84)	(253.96)	(233.25)	(260.59)	(228.34)	(67.46)	-10%	-11%	N/A	N/A
Wheat	-7	N/A	(458.07)	(464.91)	(447.97)	(420.27)	(456.42)	(486.47)	(451.37)	(420.29)	0%	1%	N/A	N/A
Pig meat	-10	N/A	(96.56)	(108.24)	(99.99)	(95.21)	(95.70)	(108.24)	(98.79)	(77.90)	-1%	-1%	N/A	N/A
Rice	-26	N/A	(160.68)	(163.40)	(159.72)	(155.19)	(158.12)	(164.76)	(157.20)	(147.54)	-2%	-2%	N/A	N/A
Groundnuts	-58	N/A	(236.97)	(382.55)	(291.29)	(252.67)	(178.15)	(430.69)	(255.49)	84.67	-25%	-12%	N/A	N/A

Source: World Bank, based on GLOBIOM model outputs; values for 2010 are based on FAOSTAT data.
Note: CSA refers to average values of following practices: agroforestry, conservation agriculture, crop diversification, drought-tolerant maize, minimum soil disturbance, residue retention and reduction of post-harvest loss. Colors indicate the relative change of net trade as a result of CSA; dark green indicates the most positive change, dark red the least positive change.

Appendix F: Public Expenditures on CSA Projects in Zambia

Table APP 17 provides an overview of all projects which promoted climate-smart agriculture in Zambia. The results stem from a survey conducted in the course of this project and may not be complete. As of 2017, major donors in Zambia dispersed a total of US$172,817,651 in Zambia through 80 agriculture and natural resource related projects (von der Decken, 2017). Based on interviews with 25 major donors and project implementers, including public sector entities, it is estimated that US$118 million was expended in 2017 on 38 different CSA related projects, reaching a total of over 1.6 million beneficiaries (Table APP 17). While this table is not a complete inventory of all CSA projects in Zambia, it provides an indication of the level of expenditure and beneficiary numbers.

Table APP 17 Summary of CSA donor projects, beneficiary numbers, and 2017 expenditures

Donor/Implementer	Project Name	Beneficiaries	Expenditure 2017 (US$)
World Food Programme	Rural Resilience Initiative (R4)	17, 835	5,300,000
Grassroots trust	Shaping a Viable Future	250,000	5,000
Grassroots trust	Legume Intercropping	2,500	5,000
Grassroots trust	Farmer Managed Natural Regeneration	25,000	3,000
Grassroots trust	Holistic Planned Grazing	20,000	2,000
ICRAF	Sustainable Agriculture Intensification	N/A	350,000
ICRAF	Sustainable Land Management	N/A	300,000
CFU	Climate-Smart Agriculture Zambia (CSAZ)	600,000	25,000,000
CFU	Regional Conservation Agriculture Program	N/A	N/A
CFU	GEF-strengthening Management Effectiveness and Generating Multiple Environmental Benefits Within and Around the Greater Kafue National Park and West Lunga National Park in Zambia	40,000	800,000
SIDA	SNV Sustainable Land Management Systems (SLMS) Project	15,000	4,000,000
Self Help Africa	Community-based Seed Enterprises and Participatory Crop Improvements, in all AEZs	2,500	4,000
Self Help Africa	Integrated Livelihoods Programme in the Northern Part of Zambia	17,000	20,000,000
Self Help Africa	Strengthening Climate Resilience in the Kafue Sub Basin (SCRika) as CRAF Under Government	164,000	N/A
Self Help Africa	Kaoma Farm Development Project in Kaoma Western Province	150	1,500
USAID	COMACO	40,000	N/A
USAID	Partnership for Innovations: Legume Seed Development for Drought Areas	50,000	3,400,000
IFAD	Smallholder Productivity Promotion (S3P)	73,000	33,400,000
IFAD	Enhancing Smallholder Livestock Investment Project (E-SLIP)	180,000	15,100,000
Finland	Empowering Local Communities to Adapt Zambezi	400	145,000
Finland	Sustaining Environmental and Natural Resources in Kawambwa	400	145,000

continued

Table APP 17 continued

Finland	Deepening Community Based Natural Resources Management in Zambia	4,000	145,000
Finland	Improved Environment and Natural Resources Management through Promotion of Sustainable Organic and Other Practices/ Technologies	2,000	137,000
FAO	Strengthening integrated adaptation planning and implementation in Southern Africa smallholder agriculture systems to support food security	6,000	400,000
European Union	Conservation Agriculture Scaling Up Project (CASU)	N/A	2,000,000
AFDB	Agriculture Productivity and Enhancement Project (APMEP)	75,000	1,500,000
AFDB	Smallholder Irrigation Project (SIP)	5,000	2,000,000
AFDB	Livestock Infrastructure Support Project	35,000	1,200,000
AFDB	Strengthening Climate Resilience in the Kafue Sub Basin (SCRika)	70,000	1,500,000
CRS	Scaling up Production Food Security and Climate Adaptation	5,600	350,000
CRS	Farmers Access to Market Engagement	600	400,000
Heifer International	Enhanced Livestock Trade and Enterprise Project Phase III (ELITE III)	3,000	N/A
Kasisi	Sustainable Organic Agriculture Support	100	550,000
Kasisi	Seed Knowledge Initiative	150	10,000
Kasisi	Push-pull project-involves pest management- using biological methods	47	20,000
Kasisi	FIBL-concerned with soil health	100	120,000
Total		**1,686,547**	**118,292,500**

Source: FAO, based on interviews with development partners conducted between July-December 2017

Appendix G: Detailed Description of Delivery Mechanisms

This appendix expands on Section 8.2. and provides a more detailed description of the mechanisms.

Weather Index Insurance—Combining Risk Transfer with Risk Mitigation

Weather index insurance (WII) is a risk transfer mechanism that can enhance livelihood resilience. Short-term shocks, such as seasonal reductions in rainfall or extreme heat, can have long-term consequences (Carter et al. 2014). To cope with resulting losses, farmers tend to reduce spending on food, which affects health and education outcomes, and exacerbates poverty. WII compensates policyholders based on a weather index that approximates losses at a particular location and period of time. As the value of the weather index surpasses a threshold and approaches the maximum limit, payment increases at an established rate (for instance, US$15 is paid for each millimeter of rainfall between threshold of 100 millimeters and 50 millimeters).

WII faces several challenges: (i) Basis risk is the greatest challenge and refers to the difference between the payout as measured by the index and the actual loss incurred by farmers. Since losses are approximated by the weather index, policyholders may not be paid when they suffer losses or they may receive a payment when they have suffered no loss. (ii) Sufficient historical weather data is necessary to establish an index. The integrity of weather stations and accurate recording of data must be ensured. (iii) Capacity building and sensitization for farmers, insurers, and regulators about the functioning of WII and the associated costs and benefits are crucial. (iv) A strict regulatory and legal framework is needed to ensure policyholders' interests are protected by law (World Bank 2011b).

In Zambia, the World Food Program (WFP) pairs WII with risk mitigation strategies and mandatory CSA adoption. This is the Rural Resilience Initiative (R4) program, which has four components: improved resource management and adoption of CSA (risk mitigation), insurance (risk transfer), livelihood diversification and microcredit (prudent risk taking), and savings (risk reserves) (WFP and OXFAM 2017). In 2017, 3,835 farmers, 50 percent of whom were women, were insured through the R4 initiative. The program offered financial education and collaborated with Zambia's Meteorology Department to strengthen product design and data management. An impact evaluation of R4 in Ethiopia demonstrated that the negative consequences of climate shocks on food security decreased. In Zambia, participants managed to increase their savings six-fold compared to 2016. The program and resulting network of farmer provides an opportunity to roll out training for sustainable management practices and crop diversification.

Similar WII initiatives are underway. For instance, alongside the electronic FISP which plans to scale up the scheme on a nearly national level and has the potential to incentvize farmers' adoption of CSA practices. WII was piloted as part of the Farmer Input Support Programme. The number of policies sold and the sum insured increased from less than 20,000 and US$2 million in 2016/17 to over 1 million and US$176 million respectively in 2017/18. This rapid scale-up was achieved by adding an index insurance cover to E-FISP, the digitized version of the government's agricultural subsidies program (World Bank, forthcoming). At the same time the scheme faces challenges with respect to transparency in payments, lack of capacity of farmers and implementors and questions related to the actual consumer demand for the insurance. Box APP 1 presents several activties the public sector can undertake to promote a transparent and effective WII scheme which incentivizes the adoption of CSA as risk mitigation strategies, and support private sector particpation.

Box APP 1 Weather Index Insurance. To maximize finance for development and crowd-in private resources to implement a WII scheme, the public sector could consider to support:

- ***Capacity building and training for farmers, insurers, and regulators***. Index insurance is a new concept for many farmers, and a rollout of the product requires intense education programs to help them understand the principle. Capacity building on risk transfer strategies should be combined with training on risk mitigation stratgies, such as adopting of climate-smart agriculture practices. Insurers may require technical assistance and extensive capacity building to enable them to undertake product development on a sustainable basis. Public sector support could include the development of guidelines and training modules for regulators and farmers, sensitization for involvement of local saving groups, and technical support to insurers to improve the contract design and meet the local realities.
- ***Ensure data availability and functioning, and integrity of weather station.*** Availability of historical, accurate, and complete data is crucial to design the index. The network of weather stations should be functional and automatic to ensure security and integrity, and avoid data tampering. The degree of integrity affects the cost of the uncertainty that would be reflected in the insurance premium. An improved weather data network could enhance the existing synergies with remote sensing data.
- ***Provide technical and operational support*** with technical reviews of existing schemes to build on lessons learned, feasibility studies that enhance targeting and product and scheme design, as well as monitoring and evaluation of the scheme.
- ***Reduce legal and regulatory risks to the policyholder and insurer.*** Before introducing the scheme, comprehensive legal and regulatory reviews should be undertaken to identify risks to the policyholders and insurers and identify risk mitigation options. A sound legal and regulatory framework ensures that contracts are legal and enforceable. Otherwise, there is a risk that WII development costs will be wasted or that policyholders will find themselves without enforceable rights. The review may also reveal that the regulator should impose special conditions on insurers to ensure that policyholders are adequately protected.
- ***Appoint an independent agency that, on behalf of the insured parties, can verify the accuracy of the payouts triggered.*** In schemes with many beneficiaries or an index that is not easily verifiable by the parties (e.g., based on satellite data), an independent agency could be appointed to verify that contracts have been carried out correctly.

Source: World Bank (2011b)

Business Partnerships with Rural Communities—Leveraging Carbon Finance

In Zambia, COMACO is a well-known example of a business model that addresses poverty, food insecurity, and conservation goals. COMACO promotes CSA practices such as organic farming, legume food crops to enhance soil nutrition, and crop rotation with agroforestry, as well as by developing community markets and premium pricing of 10 percent for farmers who apply CSA practices. COMACO specifically targets households with high food insecurity or whose practices lead to natural resource depletion (Lewis et al. 2011). COMACO addresses constraints of capacity building to enhance adoption of CSA and provides access to output markets. At regional trading centers, the raw commodities are processed into value-added products, such as peanut butter, jams, or dried fruits, or sold in larger quantities to different markets. By providing a reliable market, COMACO also supports efforts to reduce post-harvest losses and related emissions. Farmers reported that crop yields had increased between 16 percent for soybeans and 31 percent for maize and experienced less water stress (Mfune et al. 2016).

COMACO supports the adoption of CSA practices and forest conservation practices. By reducing deforestation and enhancing soil carbon sequestration, COMACO generates emission reduction credits, eligible for carbon finance. The promotion of CSA is expected to enhance soil carbon sequestration and reduce deforestation. To enhance impact on forest conservation, COMACO promotes the establishment of Green Zones, where sustainably harvested non-traditional forest products (apiaries for honey and wild mushrooms) and alternatives to destructive charcoal are implemented (World Bank 2018c). The aim is a reduction of GHG emissions on approximately 200,000 ha, of which 15,000 ha should fall under CSA practices. Following the first successful verification of carbon credits in October 2017, US$ 814,406 was paid by BioCarbon Fund to participating communities and COMACO.

Payments through the carbon fund are results-based. To sustain operations, COMACO receives support from donors. Monitoring, supervision, and reporting to verify GHG emission reductions demands a high level of technical capacity and support as well as human and financial resources. COMACO receives funding from different donors, which allows COMACO to set up emission reduction purchase agreements between rural communities and the BioCarbon Fund, as well as to finance related supervision activities and implement climate-smart agriculture and forest practices. Without donor funding, the financial viability of the business model in the early years may be jeopardized. Box APP 2 present strategies fo rthe public sector to support similar business-community partnerships.

Box APP 2 Business Partnerships with Rural Communities. Business partnerships with rural communities, which promote CSA practices, can be supported with the following activities:

- ***Ensure that the project is undertaken in accordance with regional and community development plans*** to maximize development and environmental impacts. Assist communities in engaging sustainable land management practices, which results in verifiable emission reduction. Sensitization on climate mitigation and the results-based nature of carbon finance could play a role in strengthening farmers' commitment to the project.
- ***Provide capacity building and training for farmers to adopt CSA and business skills.*** While the agribusiness is likely to provide training on CSA, the public sector can support or complement this by strengthening public extension workers' capacity and facilities, providing training on CSA, farming as a business (marketing, transport, quality control), and post-harvest handling, supporting the establishment of revolving funds or savings groups, and organizing agricultural fairs to spread information about the business model.
- ***Promote business linkages*** with producer groups, agro-dealers, and storage facilities; conduct farmer trade fairs; and conduct market research of target crops to facilitate market access and buisness linkages.
- ***Support access to credit by enhancing the capacity of commercial banks*** and strengthening the policy and regulatory environment. In Zambia, financial and non-financial lending institutes have limited institutional capacity to work with smallholder farmers. Support could include providing credit guarantees, building institutional capacity, supporting business partnerships between agribusinesses and financial institutes to better serve smallholders, or support growth of warehouse receipts financing, which is still in its infancy in Zambia (World Bank forthcoming).
- ***Invest in public goods and services considering private sector needs.*** Public good investments such as rural roads and access to energy reduce transaction costs and also support commercialization and the effectiveness of such business partnerships. Investment in agricultural research and development and dissemination of new varieties supports the development of new markets and further business partnerships in the long run.

Outgrower Schemes—Commercializing Horticulture Production

Outgrower schemes are a form of contract farming whereby binding agreements are made between producers and purchasers of agricultural products. Outgrower schemes are binding agreements, a coordinated commercial relationship. Farmers are linked with a large farm or processing plant that supports production planning, input supply, and adoption of new technologies including CSA, extension advice, and transport. The arrangement enables firms to source a product in a controlled way, obtain financial benefits (e.g., tax breaks, duty-free imports of machinery), and gain access to local markets that might not have been explored otherwise. Farmers benefit from access to markets and financial services, reduced price fluctuations, and support in achieving quality standards and technology, skills and knowledge transfers, and opportunities for seasonal employment. For a successful relationship, mutual trust and long-term business interests are required (Felgenhauer and Wolter 2009).

Outgrower schemes have been operated with varying degrees of success. An example in outgrower schemes for sugar cane in Mazabuka, southern Zambia showed that participants earned up to US$2,999 in 2012-2013 compared to US$500 in neighboring communities (Matenga 2017). At the same time, smallholders also depend on the contracting company, with asymmetries of power reflected in quality assessment and pricing of the product; there may be limited transparency and disputes over prices and contract conditions (World Bank and UNCTAD, 2004). The community in Mazabuka has experienced tension related to the significant role the scheme's income plays in the local community, in some instances benefiting some community members at the expense of others. The study showed that men tend to capture outgrower revenues while women tend to focus on food crop production (Matenga 2017).

Outgrower schemes can be combined with all types of products but often are used to source horticulture products and are combined with access to small-scale irrigation. In Zambia, small-scale irrigation often requires development and rehabilitation of small water infrastructure, permanent weirs and small-scale earth dams, and development of boreholes or solar pumps. In rural communities these are often supervised by water users associations (WUAs). Box APP 3 provides an overview of public sector activties which could support the emergence of fair and effective outgrower schemes.

Box APP 3 Outgrower Schemes. Although this contracting model is driven by the private sector, there is a role for the public sector:

- ***Promote private sector alignment*** with the principles of responsible investment and ensure compliance with social and environmental standards.
- ***Review and improve investment climate and policy and regulatory frameworks.***
- ***Support effective public and private sector dialogue*** to build (regional) markets.
- ***Support contract design and enforcement.*** The public sector can ensure contracts and agreements between parties are fair and transparent and offer access to legal services and advice.
- ***Support smallholder capacity and coordination,*** to enable farmers to engage gainfully in commercial value chains. Support the development and strengthening of producer organizations that enhance knowledge transfer, bargaining power, and transaction costs for private companies.
- ***Improve land tenure security and access to land.*** Only 6 percent of smallholders in Zambia have some form of land documentation. Most land is under the customary land regime (Hall et al. 2017). Enhancing land tenure security by improving capacity and performance of land institutions, clarifying land policies, and streamlining registration processes could facilitate participation in an outgrower scheme and avoid conflicts between the business and local communities.
- ***Invest in public goods and services considering private sector needs.*** Public good investments such as rural roads and access to energy reduce transaction costs, support commercialization, as well as the effectiveness of such business partnerships.
- ***Provide irrigation infrastructure and governance structure.*** To support horticulture, irrigation should be introduced. The public sector can provide support in the design, procurement and supervision of construction of off-farm water infrastructure design and technical support as well as procurement and supervision of construction. In addition, the public sector can improve water management, access, and governance at various levels, such as building capacity of extension staff and communities or supporting the establishment and strengthening of the WUAs that are the local-level institutional entry points for efficient management of water resources.
- ***Enhance public inspections and quality assurance to attract agribusinesses,*** such as by investing in inspection services for inputs agro-dealers and in labeling programs; strengthening the capacity of public laboratories; strengthening sanitary and phytosanitary standards (SPS), regulations, and certification; and reviewing and revising trade policies and management frameworks for strategic commodities to attract private companies and support exports.

Pluralistic Participatory Extension Approach—Supporting Linkages Between Research and Extension

The pluralistic participatory extension (PPE) approach supports different sources of advisory services to disseminate innovative CSA technologies. The results reveal that even under CSA, crop yields may not increase sufficiently to meet agriculture sector goals (Section 5). This calls for innovative approaches for agricultural extension and research. Extension and agricultural advisory services are key for spreading the adoption of CSA and achieving development goals. International evidence shows that agricultural extension visits can reduce poverty (e.g., Nkonya et al. 2009; Dercon et al. 2008). There are several extension models, such as the traditional supply-driven public extension model, private extension services including NGOs, and demand-driven, participatory, and pluralistic services. The latter recognizes the diversity of farmers and farming systems and is characterized by the coexistence of multiple public and private sector approaches, providers, funding streams, service types, and sources of information and experiences. It can include membership-based farmer organizations, private or commercial enterprises, and NGOs. Each has the potential to provide complementary services and to thereby contribute to long-term sustainability of advisory service delivery to farmers (Heemskerk and Davis 2012).

The PPE approach is way to strengthen partnerships between agricultural research, extension services, and farmers. PPE provides the opportunity for farmers' "demand articulation" to better identify the needs of different user groups and help transfer research into goods and services. This can include on-farm testing and sharing of experience with research results, development of technical options including the development and testing of climate-resilient solutions, through farmer-led trials and demonstrations. Sharing research results through PPE includes promoting farmer-to-farmer learning, farmer organization knowledge exchange networks, and access to information platforms using ICTs. In this context, farmers are organized and empowered to demand quality support services. An example is Senegal's Agricultural Services and Producer Organizations Project (1999-2011), which established a network of producer organization, strengthened research capacity, and supported the provision of demand-driven agricultural services provided by the private sector. The project improved the quality and price of groundnuts, improved the level and quality of community seed stocks, raised agricultural income by 12 percent, and raised non-farm household income. In addition, the agricultural research

Box APP 4 PPE relies on a range of service providers and a range of approaches including **Farmer Field Schools**. The public sector can play a role to facilitate private sector involvement:

- ***Coordinate pluralistic extension services,*** thereby strengthening the market orientation of services, coordination between service providers, and interaction and learning between public and private service providers; improve targeting and differentiation of services for different farmers; and enhance downward accountability to farmers and performance-based contracts.
- ***Develop sectoral or local policy that supports private sector service provision.***
- ***Develop integrated planning skills for the local governments,*** to ensure efficient coordination and management of the PPE approach and partnership with research (e.g., provide two channels for research proposals from researchers and users).
- ***Improve capacity of extension workers,*** government and digitize government procurement for greater transparency; upgrade research and extension facilities where needed.
- ***Support farmer capacity building, including the setting up of FFS:*** includes demonstrations, sensitization on the topic, identification of farmers and formation and production inputs and learning material for CSA, sensitization and awareness meetings on CSA; prioritization studies for crops; clean materials for establishing demonstration plots, seed multiplication schemes.
- ***Support development and strengthening of farmer organizations*** to better articulate farmers' demands, which allows for better matching of service providers with organizations and which improves service delivery.

system generated 22 technologies (Spielman et al. 2012). Box APP 4 elaborates which actions the public sector can take to support an effective PPE and enhnace private sector involvement.

Farmer Field Schools—Strengthening Community-based Learning and Technology Adoption

FFSs provide education and extension services, often with a focus on CSA practices. Over the years, FFSs have emerged as a complementary and reinforcing approach to traditional agricultural advisory services. FFSs leverage experiential learning and a community-learning approach (Davis et al. 2012). FFSs are season-long programs for farmers to regularly meet, learn, and experiment on relevant topics. They are based on a combination of demonstration, explanation, and evaluation of new crop technologies and include meetings on creating farmer groups, establishing demonstration plots by lead farmers, participatory evaluation of technologies, field days, and exchange visits to facilitate learning and sharing of innovations (Anandajayasekeram 2007).

FFS should not be an alternative to existing extension efforts but rather should be incorporated into those efforts. FFS interventions are often decentralized and implemented by local authorities, NGOs, community organizations, or the private sector. A study in Eastern and Southern Africa found that FFSs seem most effective if mainstreamed in a traditional extension approach. To ensure effectiveness of the program, farmer facilitators and other facilitators need to be trained better and more backstopping opportunities should be provided. The presumed farmer-to-farmer multiplier effect has not proved to be completely accurate (Anandajayasekeram 2007). Increasing the diversity of trainers, e.g., female or private sector trainers, could improve the promotion of marketing activities through the FFS approach and attract more female participants (Ministry of Foreign Affairs of Denmark 2011).

Integrated Participatory Landscape Management Approach—Achieving Multiple Objectives

The landscape management approach entails the planning of interventions at a larger level, such as a watershed, a catchment area, or a communal area, as well as planning through a participatory land management method. According to FAO, landscape management approach deals with large-scale processes in an integrated and multidisciplinary manner. Thereby it combines natural resources management with environmental and livelihood considerations. It recognizes that the cause of challenges or vulnerabilities of households or landscapes may not be site-specific but may rather involve multiple scales and multiple actors.[18] Therefore, the landscape approach aims to achieve multiple economic, social, and environmental objectives and to provide vital ecosystem services while being managed by the people using the land and producing those services (Sayer et al. 2013).

Ten principles characterize an integrated landscape approach: (i) continual learning and adaptive management to accommodate the dynamic nature of landscape processes; (ii) solutions must result from consensus-building processes that are based on trust; (iii) take into consideration the various scales at which problems occur, from the local to national levels, and how approaches can impact each level; (iv) extensive research to acknowledge the multifunctionality of landscapes, which creates competing interests for land uses; (v) stakeholders need to be iteratively identified and engaged to ensure a just distribution of benefits and incentives; (vi) solutions must result from negotiated and transparent logic to allow for the development of trust, promote good management, avoid conflict, and allow for ease in resolving conflicts that do occur; (vii) rights and responsibilities must be clarified; (viii), participatory and user-friendly monitoring to foster shared learning; (ix) threats and vulnerabilities must be identified in order to build system-level resilience; and (x) strengthen stakeholder capacity to judge, respond, and share best practices and experiences and ensure stakeholder participation and growth (Sayer et al. 2013).

CSA strategies as well as practices for forestry management, improved livestock management, or rangeland and water management, should not be analyzed and implemented in isolation, but rather under consideration of broader landscape management strategies. The introduction of CSA practices to support livelihood and ecosystem outcomes is one of many strategies in an integrated landscape approach. Community forest management is another example. This can include development of participatory land and resource use planning and management—such as fire control and prevention—and sustainable production of timber and non-timber forest products including charcoal. In addition, it is critical to introduce communal agreements for livestock grazing, agreements for the use of heritage and ancestral land, and agreements concerning water governance and rights. For integrated livestock management, the development of on-farm and community forage production and improved rangeland management through over-sowing of well-adapted leguminous species can increase productivity and environmental benefits such as increased carbon sequestration and reduced emissions from enteric fermentation.

Recent research in Zambia emphasizes the overall benefits of considering multiplied goals within a landscape approach and shows that conservation outcomes can be achieved at a lower cost when economic and ecological values of land are adequately considered. For instance, agricultural investment planning that prioritizes agronomic potential and existing road access are found to be correlated with solutions that seek to reduce carbon and biodiversity costs. This demonstrates the potential benefits of adopting a landscape approach reconciling multiplied goals, which can achieve economic benefit at the lowest environmental cost (Estes et al. 2016).

Participatory land management is a key component of the approach and seeks to involve and empower communities in decision-making and to decentralize authority. Participatory land management is the opposite of top-down, centralized, and exclusionary approaches to agriculture and natural resource management. Top-down approaches have been criticized for not only being ineffective and inefficient but also for disempowering and harming local populations. Stakeholder engagement can help reduce and resolve conflict and tension by improving trust and learning between stakeholders and greater community buy-in for decisions and projects (Dyer et al. 2013; De Vente et al. 2016). The success of this approach is partially enabled by formal processes that are organized and fair and that allow for distribution of benefits, conflict resolution, and increased trust among participants. Government participation can have varying impacts; when government actors lead the processes, learning by participants, flexibility of solutions, and development of trust are less likely to result. When government actors are involved in a minor capacity, the outcomes of the approach are more likely to be accepted by stakeholders involved in implementation (De Vente et al. 2016).

There are several examples in Zambia in which a participatory land management approach was implemented. For instance, in Zambia's Muchinga and Eastern Provinces, USAID's Community Forests Program, implemented participatory forest management approaches and supports the GoZ's REDD+ strategy from 2014 to 2019 (Huntington et al. 2018). The project aims to increase the amount of forest land under improved management, improving livelihoods through the development of non-timber forest products and alternative incomes, and reducing carbon emissions from deforestation. The project is a strong indication of the support for community land management practices and its ties to climate benefits. The World Bank-funded Zambia Integrated Forest Landscape Project similarly supports participatory land management to build capacity in rural communities and support the adoption of sustainable and low-carbon land management practices, with the ultimate goal of generating emission reduction credits that are sold to the BioCarbon Fund (GoZ 2017c).

Box APP 5 Participatory landscape management approaches are multi-stakeholder processes that can benefit from private sector investments. At the same time, the participatory nature and empowerment of local communities has to be ensured. The public sector can take following actions:

- ***Support inter-ministerial collaboration and knowledge platforms*** and increase the planning, monitoring, and policy formulation capacities of public sector stakeholders.
- ***Ensure compatibility with community, landscape, and public sector goals.*** This includes the assessment of opportunities, feasibility, goals, risks, challenges, and long-term benefits of private sector involvement, as well as monitoring and evaluation regarding whether companies stick to the commitments.
- ***Community planning:*** Support risk and vulnerability assessments; support formation of community organization and strengthening of groups; support land management/watershed planning with relevant tools (e.g., GIS, ICTs). Provide capacity building: training or link communities with service providers to address vulnerabilities in landscape. Address infrastructure and logistics materials: provide materials for land restoration, production inputs, watershed management, and forest management.
- ***Review legal and regulatory set-ups and whether there is a need for reform*** to define acceptable standards and set the frameworks at the jurisdictional or national levels within which businesses must operate, focus specifically on social and environmental standards, and identify new linkages and governance challenges that may develop from private sector involvement.
- ***Initiate dialogue and facilitate processes.*** The public sector has a critical role to play to ease and support private sector participation in multi-sectoral partnerships. NGOs and the public sector have the capacity to develop platforms for stakeholder dialogue, negotiation, and consensus building to operationalize successful landscape approaches. This could potentially build trust and mutual understanding with community. Thereby, understanding the concerns of involved private businesses can provide a starting point for building the private sector's trust.
- ***Support livestock management as integral part of a landscape approach.*** The public sector could play a critical role in developing animal husbandry/productivity assessments and implementation plans; support procurement and distribution of improved planting material; develop forage demonstration and promotion activities to support animal health services and vaccination.

Barriers to success for landscape approaches include governance issues, a lack of institutional capacity, power struggles, and lack of efficiency. Even a participatory approach is expected to experience difficulties. One critique is that participatory processes—and the inclusion of a variety of stakeholders—can lead to inefficiency, procedural failures, and difficulties in achieving success. Participatory processes can also worsen existing conflicts or result in decisions that favor particularly powerful or influential groups. Concerns also exist around the effectiveness of participatory management in dealing with issues that can be much broader than the local context (e.g., irrigation practices as they relate to water rights) (De Vente et al. 2016). However, a case study in Zambia also shows that centralized management of participatory land management can create dependencies and disempowerment in a way that runs counter to the goals of participatory land management (Dyer et al. 2013).

Despite being a multi-stakeholder process, landscape approaches often do not include the private sector. Out of 104 integrated landscape initiatives documented in Latin America and 87 in Africa, only 24 and 10 respectively involved the private sector (Milder et al. 2014). While there are opportunities for private sector involvement, i.e., influence funding, sustainable investments, and market and job opportunities, there may be a lack of skills or limitations in the existing landscape management methodologies in managing power relations that could marginalize small local business initiatives, derail the multi-functional objectives of the landscape approach, or focus too narrowly on one commodity (Namirembe and Bernard 2015). However, the private sector may find landscape approaches increasingly interesting as a means to mitigate risks and to address opportunities beyond the production unit (Kissinger et al. 2015). Each landscape has its own context, stakeholders, and power relationships that will affect solutions needed in a particular location. Box APP 5 provides suggestions for public sector actions to support the implementation of landscape approaches.

Cash Transfers—Alignment with Agricultural Planning and Programs

Cash transfers can promote agricultural production while combatting poverty and hunger and strengthening human capital for future generations. Access to capital, particularly for rural populations in extreme poverty, is largely nonexistent. Cash transfer programs are part of social protection programs, are unconditional, and designed to improve food security, health and nutritional outcomes. Evidence shows that they have economic impacts, and in particular incentivize agricultural activity. Cash transfers provide infusions of capital as an incentive to invest in agriculture. As such, they can be combined with the introduction of CSA practices. They allow participants to overcome the constraints of upfront investment cost to adopt CSA practices, which, at the same time, have the potential to enhance livelihood resilience, which is critical for the rural poor. Evidence shows that cash transfers can increase agricultural production as well as self-sufficiency due to the improved standing and economic status of participating households. In this way, the cash transfers help households surmount an initial barrier to upward socioeconomic mobility (Boone et al. 2013; Tesliuc 2013).

In the context of Zambia, some argue that cash transfers are needed to lift households out of in extreme poverty (Tesliuc 2013). Some argue that the chronic nature of poverty for many small farmers makes them incapable of achieving and maintaining food security without some sort of supplementary support. It has already been recommended that revisions to the existing FISP program include cash transfers, particularly during nonproductive agricultural seasons and for households with very small land sizes (Boone et al. 2013).

At the same time, cash transfers are criticized for being a "band-aid solution" and for providing a one-time support, which is not sustainable in the long term. Other critiques vary based on the guidelines associated with cash transfers. For instance, that they create dependency of poor households on the government, or that providing cash to the poor leads them to work less and live off the transfer. However, evidence shows that this is not necessarily the case, but that they promoted promoted productivity and provided an income multiplying effect at the household and local economy level (FAO 2014).

Cash transfers have the potential to support the start-up and maintenance costs for agricultural technology adoption and increased agricultural productivity. A case study in Malawi shows that cash transfers can help build capacity for extremely poor farming households to expand agricultural production (Boone et al. 2013). Recipient households purchased a greater quantity of agricultural implements, such as shovels and chickens. More recipients used their own farms as their primary or secondary source of income and reduced their engagement in low-wage labor elsewhere and subsequently produced a greater variety and quantity of food on their own farms. The transfers also improved children's nutrition and education. The study reported that cash transfers should be used as part of a larger suite of agricultural strategies; in Malawi, they were complemented by the large-scale fertilizer subsidy program.

Evidence from Zambia shows that cash transfers had positive impacts on household livelihood strategies. Zambia's Child Grant Programme led to a 34 percent increase in cultivated land and to an increase in input use, such as seeds, fertilizer and hired labor. This led to an increase in the value of overall production of 50 percent, which was largely sold and even led to an income multiplier effect. the evaluation found that the increase in per capita consumption induced by the programme was 25 percent greater than the transfer itself. In addition the programme led to a shift from agricultural wage labor to on-farm activities for adults, and more time in family agricultural and non-agricultural businesses (FAO 2014). Thus aligning cash transfers with agricultural planning and programmes such as extension services and training on climate-smart agriculture and time it in a way that support agricultural activities most (for instance before the planting season) could have a sizable impact on rural livelihoods.

Gender-Sensitive Supply Chains—Facilitating Access to Assets and Services for Women

In sub-Saharan Africa, women rarely have access to the same markets and resources as men, which inhibits their potential success in cultivating crops. It is well documented that socioeconomic barriers prevent women from having equal access to land, market, education, and networks. This inequity is worsened by the additional time pressure that women face in managing their complex workloads, or complicated familial gender roles. Case studies in Ghana and Uganda confirm the negative impacts of gender imbalances on farming, particularly in the context of cash crop production. In Ghana, women's access to liquid capital for purchasing inputs was limited, which led women to use sub-optimal production technologies. These sub-optimal technologies require more labor and land, which generate even greater costs and difficulty. In Uganda, the barriers for producing and marketing large quantities of crops and the lack of access to affordable transportation limited women to selling at markets where they received lower prices for their products. In addition, gendered power dynamics are also reported to lead to women having smaller pieces of land or land that is less fertile (Hill and Vigneri 2011).

There are several gender-sensitive strategies to enhance access to the same resources and markets as men, leading to relatively equal chances at success. Improving the gender-sensitivity of supply chains can entail transportation support for female farmers to get their crops to more optimal markets; fostering fair access to capital for female farmers; developing mechanisms to ensure fairness in land allocation to women; and providing women with valuable trade knowledge and insights that might otherwise be withheld from them. If implemented, these strategies can help to improve agricultural productivity by enabling women to produce to their full potential and improve their welfare and local socioeconomic standards (Hill and Vigneri 2011; Elbehri 2013). In fact, research shows that when women have access to the same resources and markets as men, they have relatively equal chances at success (Hill and Vigneri 2011).

Gender-sensitive supply chains support the adoption of CSA practices. These supply chains help to grow the farming operations of female farmers, who can obtain improved access to capital as part of supply chains that provide them equal opportunity. Access to capital can alleviate the barriers to adopting improved agricultural strategies. Gender-sensitive supply chain development can also entail increasing women's access to education and training, for instance though participation in FFSs targeted to women.

Appendix H: Stakeholders Consulted During the Preparation of this Report

Zambia Climate-Smart Agriculture Investment Plan Preliminary Results Stakeholder Workshop April 18 -19, 2018	
Name	Organization
Amanda Palazzo	International Institute for Applied Systems Analysis (IIASA)
Antony Chapoto	Indaba Agricultural Policy Research Institute (IAPRI)
Arend Van Der Goes	SNV Netherlands Development Organization
Dailes Judge	Oxfam
Dominic Namanyungu	Ministry of Agriculture; lead of CSA Technical Team
Dorothy Mwape	Solidaridad
Douglas Mwasi	Catholic Relief Service
Etinala Tembo	PELUM Zambia
Eustensia Munsaka	Indaba Agricultural Policy Research Institute (IAPRI)
Festus Hanankani	iDE Zambia
Frank M Kayula	National Union for Small-Scale Farmers (Nusfaz)
Friedrick Mahler	European Commission
Gillian Phiri Namuchimba	Future Seeds
Hary Ngoma	United States Agency for International Development (USAID)
Henry Longo	Care International
Henry Mgomba	Ministry of Agriculture
Ignatius Mwale	Future Seeds
Julia Kirya	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
Julius Shawa	PS Agriculture; Ministry of Agriculture
Kinkese Theresa	Indaba Agricultural Policy Research Institute (IAPRI)
Michiel Van Dijk	International Institute for Applied Systems Analysis (IIASA)
Misael Kokwe	Food and Agriculture Organization (FAO)
MM Kawamwa	MF
Monde S. Zulu	Zambia Agricultural Research Institute (ZARI)
Morton Mwanza	Ministry of Agriculture
Mumba Mwape	Zambia Agricultural Research Institute (ZARI)
Munalula Akayombokwa	SNV Netherlands Development Organization
Mundia Silumesi	Seed Control and Certification Institute (SCCI), Ministry of Agriculture
Munkombwe Graybill	Zambia Agricultural Research Institute (ZARI)
Musonda Kapena	n/a
Mwila Chikwekwe- Weijmer	Agence Française de Développement (AFD)
Mwimbu Ngoma	Heifer
Nick Sitko	Food and Agriculture Organization (FAO)
Norman Chisamo	OXFAM
Nyambe Kwalombota	Cotton Board of Zambia (CBZ)
Olipa Zulu Mbata	World Food Program (WFP)
Patricia Hlangayo	World Agroforestry Centre (ICRAF)
Peter Manda	VUNA
Phillip Siauyebe	Ministry of Agriculture
Richard Mumba	Community Markets for Conservation

continued

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Silke UHLENBROCK	World Fish
Simunzi Simunzi	Golden Valley Research Trust (GART)
Susan Chuala	Future Seeds
Sven Genscitick	World Fish
Sydney Mwamba	Seed Control and Certification Institute (SCCI), Ministry of Agriculture
Tamala Tonga Kambikonse	University of Zambia (UNZA)
Theresa Gondwe	International Institute of Tropical Agriculture (IITA)
Vincent Akamandisa	Zambian Forum for Agricultural Extension and Advisory Services (ZAFAAS)
Joseph Mwanza	NWK
Joseph Mbinji	Oxfarm
Golden Mahove	Vuna
Henry Mgomba	MoA –Advisory Services
Coillard Hamusimbi	Zambia Natinal Farmers Union
Tarisayi Pedzisai	ICRISAT
Matongo Munsaje	MFL
Vernacious Mulenga Musonda	MFL
Geoffrey Heinrich	CRS
Friedrich Mahler	EU
Henry Loongo	CARE International (CARE
Mike Mailloux	Conservation Farming Unit(CFU)
Kelly Toole	DFID Africa Regional Department
Andrew Chongwe	Ministry of Fisheries and Livestock
Antony Chapoto	IAPRI
Christine Yamba Yamba	Ministry of Fisheries and Livestock
Gilbert Kaimana	Zambia Sugar
Given Simalumba	Ministry of Fisheries and Livestock
Horeward Tembo	ZARI
Micheal Isimwaa	Ministry of Fisheries and Livestock
Mishake Nyembe	Ministry of Fisheries and Livestock
Stanlous M.Chisakuta	MoA-TSB
Swithine H. Kabilika	Ministry of Fisheries and Livestock
Allan Mulando	World Food Programme
Kundhlande, Godfrey	World Agroforestry Center (ICRAF);
Miguel Lizarazo	CIAT
Herbert M. Mwanza	ACT
Prof Yamba	University of Zambia
Gibison Simusokwe	CFU
Richard Mumba	COMACO
Bruno Mweemba	Biofin-UNDP
Dr Fusya Y. Goma	NALEIC
Lewis Bangwe	African Development Bank
Dr. Kalaluka Munyinda	University of Zambia
Dr. Elijah Phiri	University of Zambia
Edison Nkonde	Zambia Meteorological
Dr. Mick Mwala	CSA- Consultant

Other Occasions	
Name	Organization
Wallace Mayiya	Alliance for Nutrition and Reconstruction
Dr. Francis M. Mulenga	Department of Veterinary Services; Ministry of Fisheries and Livestock
Nefuno Kabwe	Ministry of Development Planning
Henry Loongo	Care International
Dale Lewis	COMACO
Mick Mwala	University of Zambia

Zambia Climate Agriculture Investment Plan: Inception Workshop October 16 and 17, 2017; Lusaka, Zambia	
Name	Organization
Akabiwa Nyambe	National Designated Authority (NDA) for the Green Climate Fund
Andrew Songiso	Ministry of Agriculture
Antony Chipoto	Indaba Agricultural Policy Research Institute (IAPRI)
Arend van der Goes	SNV Netherlands Development Organization
Ballard A.M Zulu	Indaba Agricultural Policy Research Institute (IAPRI)
Beene Miyala	Ministry of Agriculture - National Agriculture Information Services
Brian Chisanga	Indaba Agricultural Policy Research Institute (IAPRI)
Cecilia Brumer	Embassy of Sweden
Chance Kabaghe	Indaba Agricultural Policy Research Institute (IAPRI)
Charles Sondashi	Ministry of Agriculture (MoA)
Christabel C. Chabwela	Indaba Agricultural Policy Research Institute (IAPRI)
Douglas Mwasi	Catholic Relief Service (CRS)
Frank M. Kayula, Dr.	National Union for Small-Scale Farmers (Nusfaz)
Friedrick Mahuer	European Commission
G. Chigeza	International Institute of Tropical Agriculture (IITA)
Gelson Tembo	University of Zambia / PALM
Hambulo Ngoma	Michigan State University—Indaba Agricultural Policy Research Institute (IAPRI)
Idriss Ali Nassah	World Fish
J. Mondy	World Food Programme (WFP)
M. Mwale	Zambia Agricultural Research Institute (ZARI)
Mick S. Mwala	University of Zambia (UNZA)
Milu Muyanga	Michigan State University
Misael Kokwe	Food and Agriculture Organisations
Morton Mwanza	Ministry of Agriculture
Nyambe Kwalombota	Cotton Board of Zambia (CBZ)
Palazzo Amanda	International Institute for Applied Systems Analysis
Paul Samboko	Indaba Agricultural Policy Research Institute (IAPRI)
Peter Manda	VUNA
Rhoda Mukuka	Indaba Agricultural Policy Research Institute (IAPRI)
Robby Mwiinga	OXFAM
Sebastien Grey	International Centre for Tropical Agriculture (CIAT)
Stanley Ndhlovu	World Food Programme (WFP)
Stanly Ndhlovu	World Food Programme (WFP)
Tamara T. Kambikambi	University of Zambia (UNZA)
Theresa Gondwe	International Institute of Tropical Agriculture (IITA)
Vincent Mofya	Kasisi Agricultural Training Centre (KATC)

Endnotes

1. IMPACT is a partial equilibrium model that is used to simulate agricultural development at the global level (but also include national representation) under a range of future scenarios. In the cited study, three socioeconomic (pessimistic, baseline, and optimistic) and four climate change scenarios were combined to account for the large uncertainty in both types of drivers. All three socioeconomic scenarios showed GDP and population increases between the base year and 2050.
2. For instance, cassava yields are expected to decline by 2.9 percent compared to a business as usual scenario, cotton by 6.5 percent, groundnuts by 5.2 percent, maize by 8.7 percent, and soybean by 3.0 percent, while rice yields are expected to increase following climate change by 3.4 percent.
3. The development objective of this task is "to identify and prioritize key policy actions, investments and knowledge gaps. The development of the plan will build on existing knowledge, foster dialogue, and build client capacity to operationalize country climate commitments towards a productive, resilient, and low-emissions agriculture sector."
4. GHG emissions in 2050 as modeled in GLOBIOM indicate that under limited international support (reduction of 25%) (substantial international support) LULUCF sector could emit 56 $MtCO_2e$ (39 $MtCO_2e$) emission, and save 18.8 $MtCO_2e$ (35 $MtCO_2e$)emission compared to a business-as-usual scenario in 2050. With limited (substantial) international support the agriculture sector could emit 5.3 $MtCO_2e$ (3.7 $MtCO_2e$) emission and has to save 1.8 $MtCO_2e$ (3.34 $MtCO_2e$) emission compared to a business-as-usual scenario in 2050.
5. The High-Level Commission on Carbon Prices, led by Joseph Stiglitz and Nicholas Stern, concluded based on an extensive review that a range of US$40-80 per tCO_2e in 2020, rising to US$50-100 per tCO_2e by 2030, is consistent with achieving the core objective of the Paris Agreement of keeping temperature rise below 2 degrees, provided a supportive policy environment is in place (Carbon Pricing Leadership Coalition 2017).
6. The yield boost from adopting these practices increases the economic returns for these particular crops over other crops on land that may be less productive, therefore the expansion of cropland or switch to these crops reduces the overall yield.
7. Calorie availability is a measure of the total final demand of households or of food available for consumption, which does not include retail waste but does include household waste.
8. The FAO projects a continuation of the diet transitions for developing countries such as Zambia, where calorie availability increases over time due to the increase in GDP per capita and results in an increase in animal products.
9. Kanyanga et al. (2013) project a range of 1,600-2,400 kcal/cap/day for only a subset of crops and assume slower economic growth. Using the same modeling approach, IFPRI (2017) has more recent projections for food availability showing an increase in Zambia to 2,250 kilocalories by 2030 and to 2,640 by 2050. The projections used here are in line with IFPRI's projections.
10. The Zambia NDC (2015) states that through 2030, estimated emission could be reduced by 38,000 $GgCO_2e$, as compared to 20,000 $GgCO_2e$ under domestic efforts with limited international support. This translates into a reduction potential of 25 percent and 47 percent against 2010 as the base year for the domestic efforts with limited international support and domestic efforts with substantial international support, respectively (GoZ 2015)
11. This approach was chosen due to limited information in the NDC document about the baseline scenario. In addition, GLOBIOM can only present 6 emission categories in the LULUCF and agriculture sector. We assess whether the target of 25 or 47 percent is reached in each category.
12. In Zambia, the conversion of grassland to cropland releases carbon stocks (above and below ground) of about 6.8 tCO_2e/ha on average (max: 18.35; min: 5.28) based on the Global Biomass Carbon Map (Ruesch and Gibbs 2008; Gibbs et al. 2008). Additionally, conversion of natural land to cropland releases 172.51 tCO_2e/ha on average (max: 220.61; min: 142.7) and conversion of natural land to grassland releases 165.7 tCO_2e/ha on average (max: 212.45; min: 137.40).
13. The net carbon balance was calculated with the accounting tool EX-ACT. The analysis compared a without project scenario with conventional practices with a scenario where minimum soil disturbance is adopted on 49 percent of smallholders. It is based on data from GLOBIOM: 49 percent adoption rate for minimum soil disturbance practices resulting in 997,859 ha under cultivation; avoided deforestation for cropland on 43,000 ha cropland and conversion of forest and natural areas into grassland in the same extent. Nitrogen fertilizer use decreases by 5 percent.
14. For instance, in the 2007 National Policy on the Environment; the National Agricultural Policy 2012-2030 dated 2011; the 2012 Livestock Development Policy; the 2013 National Agriculture Investment Plan (2014-2018); the 7th National Development Plan from 2017; and the 2016 National Agricultural Extension and Advisory Services Strategy (NAESS).
15. The BioCarbon Fund Initiative for Sustainable Forest Landscapes is a multilateral fund, supported by donor governments and managed by the World Bank. It promotes reducing greenhouse gas emissions from the land sector, from deforestation and forest degradation in developing countries (REDD+), and from sustainable agriculture, as well as smarter land-use planning, policies and practices (https://www.biocarbonfund-isfl.org; accessed December 2018).
16. The Standard Conversion factors (SCF) is calculated as follows: SCF= SER/OER where OER is the Official Exchange Rate and SER is the Shadow Exchange Rate. SER= ([(M + Tm) + (X - Tx)]/ (M + X)) * OER, where M= total imports, X = total exports, Tm = import taxes, and Tx = export taxes. Average imports and exports over the 2010-15 period have been used for computing the SER, which is set equal to 9.83 Zmw/US$. Given that the OER is equal to 8.9 ZMK/US$, it is found that SCF=1,079. Since in Zambia a VAT of 16% is also applied to all tradable goods, the final SCF is 0,928. Market prices of all tradable goods are converted in economic prices by applying the SCF.
17. These conversion factors are calculated on the basis of World Bank projections for the year 2025 expressed in 2010 constant prices and adjusted to 2016 current prices using the weighted index for each category of commodity index (World Bank; commodity price forecasts; Pink sheet). Import parity prices are computed for fertilizers (Urea, Phosphate and Compound D), which are among key imported items, starting from the international FOB prices at nearest port and considering tariffs and taxes, marketing charges, and transportation costs. Export parity price is computed for soybeans, one of the major exportable crop commodities.
18. http://www.fao.org/land-water/overview/integrated-landscape-management/en/, [last accessed December 2018]

PRODUCTIVITY RESILIENCE LOWER EMISSIONS

CLIMATE-SMART AGRICULTURE INVESTMENT PLAN
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