ADAPTATION ROADMAP FOR THE AGRICULTURAL SECTOR

EASTERN PROVINCE

ZAMBIA

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Strengthening the Drought Resilience of Zambia's Agricultural Sector –

Developing Adaptation Roadmaps for the Agricultural Sector of the Eastern and Southern Provinces

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EXECUTIVE SUMMARY

Zambia's Eastern Province is highly exposed to drought, and climate change is expected to intensify both the frequency and severity of drought impacts in the coming decades.

This document presents a quantitative assessment of future drought risks and evaluates adaptation pathways that can reduce economic losses, protect livelihoods, and strengthen food security under moderate (RCP 4.5) and severe (RCP 8.5) climate change scenarios. By combining climate risk modelling with an economic evaluation of adaptation measures under different budget scenarios, the analysis moves beyond qualitative vulnerability assessments and offers an evidence-based foundation for adaptation planning, investment prioritization, and policy development at the provincial level.

The drought risk assessment shows that maize and cattle are the most vulnerable and economically significant assets in the Eastern Province. Maize dominates projected crop losses due to its large cultivation area and sensitivity to rainfall variability, while cattle losses reflect both high asset values and exposure to water and feed shortages during drought years. Under future climate conditions—particularly under RCP 8.5—drought-related damages increase substantially in the absence of adaptation, translating into higher food insecurity, income losses, and stress on rural livelihoods. These risks underscore the urgency of proactive adaptation.

To address these challenges, the analysis assesses three adaptation pathways: Effectiveness, Improving Food Security, and Green Sustainable Future. Each pathway represents a distinct policy focus and protects different assets. The Effectiveness Pathway delivers the largest and most immediate reductions in drought damages, particularly for cattle and maize, and performs strongly even under limited domestic budgets. The Food Security Pathway focuses on protecting people by reducing drought-induced food insecurity through early warning systems and climate information services, post-harvest storage, and nutrition-sensitive measures. The Green Sustainable Future Pathway is largely crop-focused, with benefits concentrated on maize and other key crops, and emphasizes long-term resilience through climate-smart agriculture, agroforestry, and drought-tolerant crop varieties.

Across all pathways and climate scenarios, the results show that adaptation investments consistently reduce drought damages and protect people. Higher budgets lead to higher absolute benefits, with international investment scenarios enabling large-scale reductions in crop and livestock losses. At the same time, domestic investments often achieve higher benefit–cost ratios, demonstrating that even relatively small national budgets can deliver significant outcomes when targeted to high-risk assets and districts. This finding highlights that adaptation can—and should—begin sooner rather than later, without waiting for large-scale external finance.

Overall, this document indicates that drought risk in the Eastern Province is increasing; however, targeted adaptation can mitigate some of the damage, depending on the budget allocated. No single pathway dominates across all objectives; instead, pathway choice should be guided by policy priorities—whether protecting high-value assets, reducing food insecurity, or building long-term crop resilience. The pathway-based approach employed in the analysis serves as a starting point for adaptation planning, providing quantified estimates of damages avoided and people protected that can inform district agricultural plans, national policy processes, and climate finance applications. By acting early, targeting investments strategically, and scaling up successful measures over time, the Eastern Province can significantly reduce drought impacts and strengthen resilience under a changing climate.

To explore more about drought risk and adaptation in the Eastern and Southern Provinces, please visit our **Drought Risk & Adaptation Dashboard**. This interactive platform visualizes results and allows you to generate customized reports according to your interests.

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ABBREVIATIONS

AAAP	Africa Adaptation Acceleration Program
ADF	African Development Fund
AF	Adaptation Fund
AFD	French Agency for Development
AfDB	African Development Bank
APHLIS	African Postharvest Losses Information System
BIM	Barbados Implementation Modalities
BMZ	Federal Ministry for Economic Cooperation and Development
CCARDESA MDTF	Centre for Coordination of Agricultural Research and Development for Southern Africa Multi Donor Trust Fund
CLIMADA	CLIMate ADAptation (modelling tool)
CSA	Climate Smart Agriculture
DEFRA	UK Department for Environment, Food & Rural Affairs
DIHR	Danish Institute for Human Rights
ECA	Economics of Climate Adaptation
FCDO	UK Foreign, Commonwealth & Development Office
FISP	Farmer Input Support Programme
FRLD	Fund for Responding to Loss and Damage
GCF	Green Climate Fund
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit / The German International Development Agency
IBRD	International Bank for Reconstruction and Development
IFAD	International Fund for Agricultural Development

IFRC	International Federation of the Red Cross and Red Crescent Societies
IKI	International Climate Initiative
IPC	The Integrated Food Security Phase Classification
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
KFW	German Development Bank
LDCF	Least Developed Countries Fund
MDB	Multilateral Development Banks
NAP	National Adaptation Plan
NDC	Nationally Determined Contributions
ODA	Official Development Assistance
OPEC	The Organization of the Petroleum Exporting Countries
PIK	Potsdam Institute for Climate Impact Research
RCP	Representative Concentration Pathways
SADC	Southern African Development Community
SIDA	Swedish International Development Cooperation Agency
TRALARD II	Transforming Landscapes for Resilience and Development, second phase
UNFCCC	United Nations Framework Convention on Climate Change
UNU-EHS	United Nations University Institute for Environment and Human Security
USAID	United States Agency for International Development

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1.

INTRODUCTION

Zambia's Eastern Province is a major rain-fed agricultural area with extensive maize and groundnut production, where most farmers rely on smallholder systems with limited irrigation or financial buffers.

In the 2023/24 season, a late onset of rains was followed by a pronounced dry spell from around 20 January 2024, coinciding with the main growing period. The Presidential disaster declaration in February 2024 reported that about 2.2 million hectares of maize had been planted nationally, of which approximately 1 million hectares were adversely affected across 84 of 116 districts, including those in Eastern Province (Ministry of Foreign Affairs of Zambia 2/29/2024). According to the International Federation of the Red Cross and Red Crescent Societies (IFRC) and government sources, approximately 1 million farming households in eight provinces were affected by the drought (IFRC, 2024).

For the Eastern Province, where livelihoods heavily depend on rain-fed maize and groundnuts, these conditions translated into sharply reduced yields and local crop failures, undermining both household food stocks and income from surplus sales. The Joint Drought Rapid Assessment by the Food Security Cluster in 27 priority districts found that staple foods were often unavailable in local markets, 51.7% of surveyed households had a poor Food Consumption Score, and around 2.3 million people were moderately food insecure, while 0.6 million were severely food insecure (Food Security Cluster and WFP 2024). The Integrated Food Security Phase Classification (IPC) Acute Food Insecurity Analysis for April–September 2024 highlights Eastern as one of the provinces facing the most critical food security and nutrition challenges: around 861,800 people (≈33% of the rural population) are in Crisis or worse (IPC Phase 3+), and Eastern records about 51% of households with poor Food Consumption Scores, the second-highest share nationally after Western Province (IPC 2024).

The 2024/25 drought thus demonstrates how quickly mid-season dry spells in Eastern Province's smallholder systems become large production shocks, leading to food consumption gaps, erosion of assets, and increased reliance on negative coping strategies. The Adaptation Pathways outlined in this Roadmap are specifically tailored to the drought-risk profile in the Eastern Province, aiming to enhance the resilience of crops, livestock, and rural livelihoods against future dry spells.

WHY THIS ROADMAP MATTERS

Zambia's agricultural sector remains highly exposed to drought risks, yet systems for monitoring drought, assessing vulnerability, and preparing for drought damage need to be strengthened at the local level. Evidence from the recent 2023/24 drought in Zambia indicates that provincial and district authorities are rarely involved in systematic drought monitoring or vulnerability assessments, which limits their ability to detect emerging drought conditions, understand local impacts, and act early. As a result, responses to drought are largely reactive, with support often reaching affected communities only after significant crop losses, livelihood disruption, and food insecurity have already occurred. (Mwape et al. 2025)

Although national frameworks and district planning instruments exist, their translation into operational, locally informed drought planning in these provinces needs to be improved. This Adaptation Roadmap directly addresses these gaps by providing a data-driven and locally relevant foundation for proactive drought risk management, helping decision-makers in Eastern and Southern Provinces prioritize adaptation actions, guide investments, and move from crisis response toward long-term resilience building.

This Adaptation Roadmap is a hands-on policy and planning document that presents a comprehensive picture of current and future drought-related losses and damages in the agricultural sector of the Eastern Province. It goes beyond general policy guidance by quantifying climate risks and comparing adaptation options through a cost–benefit lens. In doing so, a representative time horizon until 2050 is assumed for the underlying analysis, while considering moderate and severe climate change scenarios (RCP 4.5 and RCP 8.5, Representative Concentration Pathways).

The Roadmap includes:

- A climate risk assessment for present and future drought scenarios for crops, livestock, and people
- Quantified potentially avoided damages and benefit–cost analysis of Adaptation Pathways
- An investment plan outlining priority measures
- Guidance on potential financing options and entry points

In doing so, the Roadmap connects high-level policy ambitions with concrete, data-driven recommendations for implementation. It demonstrates not only why adaptation is needed, but also which actions could offer the greatest return and how they can be financed.

The analysis underpinning the Roadmap uses the CLIMADA risk modelling tool to assess drought hazards and estimate expected damages to agricultural assets and livelihoods. CLIMADA simulates event probabilities, quantifies damages at multiple scales, and evaluates the cost-effectiveness of various adaptation measures under different climate scenarios. This modelling is complemented by stakeholder engagement and contextual data collection to ensure that recommendations are realistic, relevant, and aligned with Zambia's socio-economic developments.

To enhance usability, the Roadmap is structured in modular sections, allowing readers to explore climate risk insights, Adaptation Pathways, or investment guidance independently. A detailed technical annex supports the main document by explaining modelling methods, key assumptions, stakeholder processes, and underlying datasets.

The findings of this analysis provide actionable insights for government institutions, development partners, civil society organizations, and the private sector. They highlight the magnitude of drought risk facing Zambia's agricultural sector and present forward-looking options to reduce these losses effectively. Importantly, the quantified results can directly support efforts to mobilize climate finance—from both domestic and international sources, for instance, by providing evidence-based inputs for funding proposals to major climate finance institutions. The Adaptation Pathways identified also serve as valuable contributions to ongoing national policy processes, including the refinement of NAPs, NDCs, and sectoral development strategies.

Ultimately, this Roadmap is designed to accelerate the transition from climate risk understanding to adaptation action, supporting Zambia's long-term goal of safeguarding its agricultural systems and strengthening the resilience of its people.

2.

DROUGHT RISK ASSESSMENT

2.1 FUTURE DROUGHT FREQUENCIES AND INTENSITIES

Please refer to Chapter ***Drought Hazard Modelling*** *in the technical Annex for further details.*

In line with the goal of transitioning from risk understanding to adaptation action, the foundation of this Adaptation Roadmap outlines the current and anticipated future drought risks. In this section, we provide a brief introduction to the conducted drought intensity analysis, considering the current drought risk expressed in historical SPEI values (based on the years 1986-2025), as well as expected future (2050) SPEI values for the two considered RCP scenarios.

In the baseline climate, a drought with a 10-year return period, i.e., a relatively high-frequency drought, reaches SPEI values of down to –1.35 in the central (Mambwe–Chipata–Lumezi) and northern parts of Eastern Province, corresponding to a severe drought (Figure 1, left). By 2050, under the moderate climate change scenario (RCP 4.5), 10-year droughts are projected to intensify markedly, with values of up to –2.9 on the SPEI scale, i.e. extreme drought conditions. At the same time, the spatial pattern shifts, with the highest intensities occurring predominantly in the southern districts of Petauke and Sinda. Under the severe climate change scenario (RCP 8.5), this geographical pattern remains broadly similar, with very high intensities concentrated in the south and additionally in the northern Chasefu district; however, droughts further deepen, with SPEI values expected to reach about –3.35 (Figure 1, below).

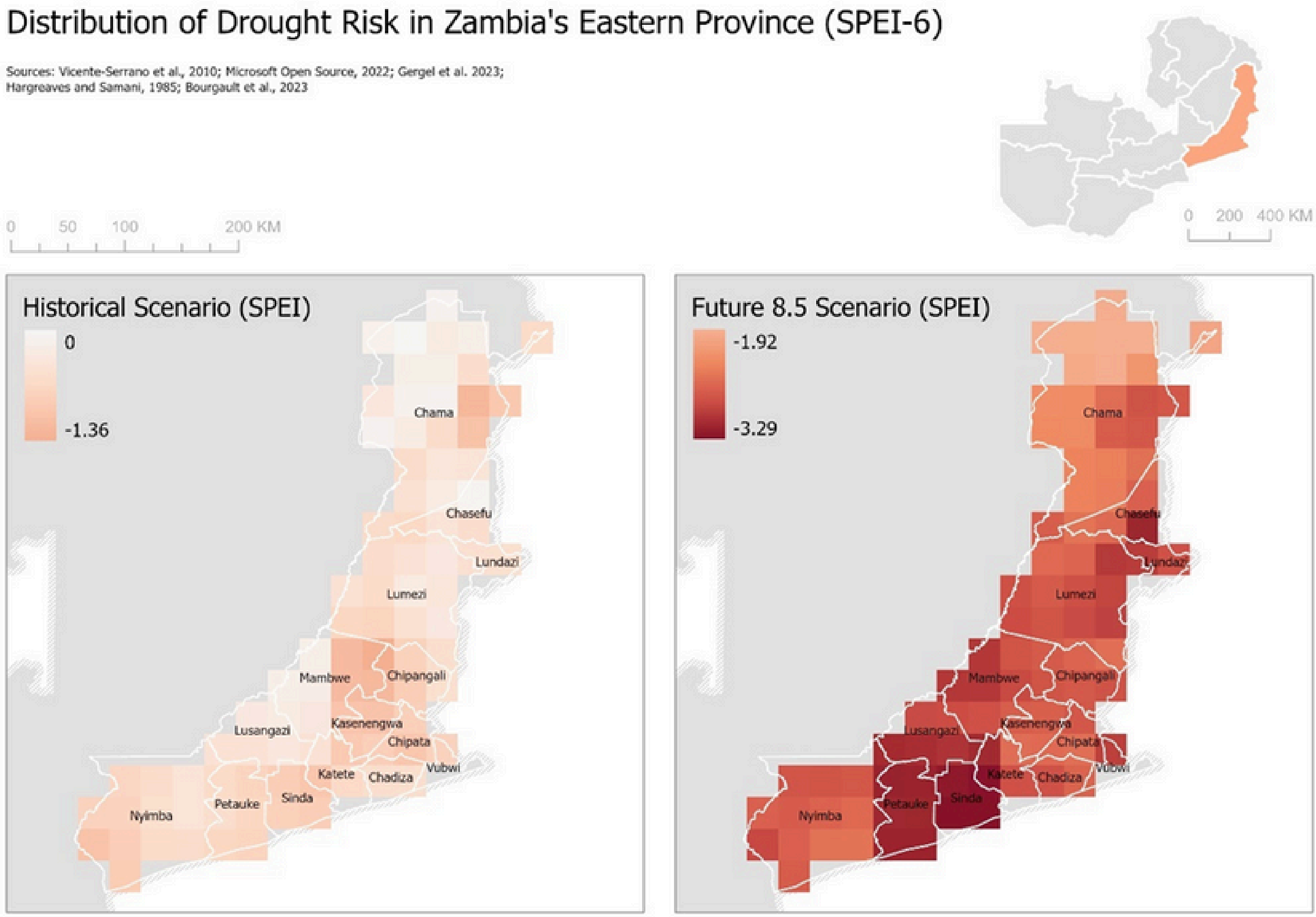


Figure 1: Distribution of Drought Risk in Zambia's Eastern Province (SPEI-6).

2.2 FUTURE DROUGHT DAMAGES IN THE AGRICULTURAL SECTOR

Please refer to Chapter ***Project Initiation & Scoping*** *and* ***Risk and Vulnerability Assessment*** *in the technical Annex for further details.*

This chapter provides a systematic and in-depth overview of the modeled impacts that droughts are projected to have on the agricultural sector by the year 2050. To assess this, we examined the impacts of drought on the key agricultural assets of respective crop and livestock types, as well as on people and their food security levels. The results show that drought impacts are projected to increase in all categories, with projections based on the severe climate change scenario (RCP 8.5) suggesting increasingly severe drought-related future damages compared to the moderate climate change scenario (RCP 4.5). This also highlights high uncertainties in modelling drought damages for the year 2050, as the developments depend on how climate change unfolds in the future and which global mitigation measures are implemented.

Following this, the drought-related damages are explained for all key assets, accompanied by maps that showcase local differences in drought damage for each asset. The drought damage maps are complemented by charts comparing today's and future drought damages, also including a monetary perspective by adding the amount of USD that would be lost if droughts fully unfold without additional adaptation measures being taken.

In the Eastern Province, droughts already cause, on average, USD 12 million in damages annually to the key assets. In the future, considering climate change and economic development, these average annual losses are projected to amount to USD 86 million by 2050 under the moderate climate change scenario (RCP 4.5). For the severe climate change scenario (RCP8.5), where climate change unfolds fully without substantial mitigation measures taken on a global scale, these losses are calculated to be on average USD 113 million for the agricultural key assets in Zambia's Eastern Province. Figure 2 illustrates the average expected annual drought damages for the present and future years in USD.

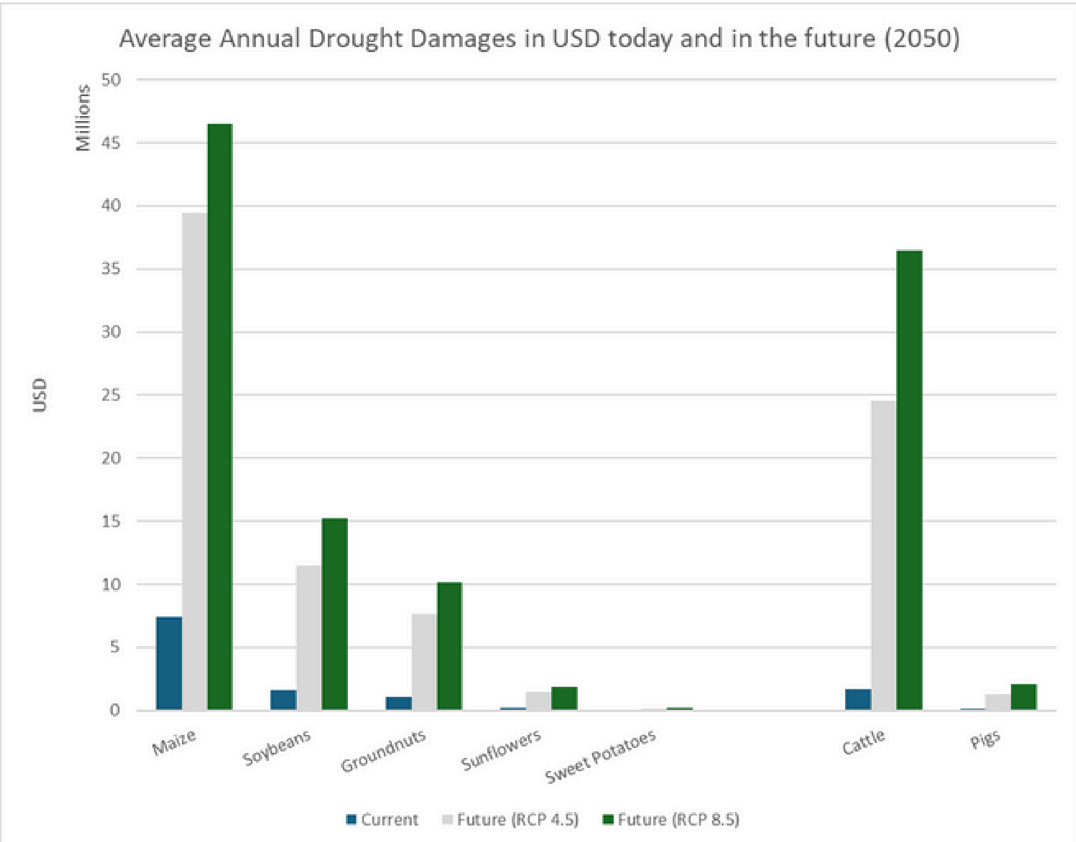


Figure 2: Average Annual Drought Damages in USD today in the future (2050).

2.2.1 DROUGHT IMPACTS ON CROPS

Droughts are already impacting crop production and harvest volumes in Zambia today and are likely to continue doing so in the future under climate change. Already today, in the Eastern Province, the average expected annual crop losses due to droughts are 44,000 tonnes every single year.

By the year 2050, the average expected annual crop losses under the severe climate change scenario (RCP 8.5) are estimated to amount to 400,000 tonnes. The largest portion of these losses would be the annual maize losses, projected to amount to 250,000 tonnes, followed by soybeans at 86,000 tonnes. Figure 3 illustrates the share of future crop losses in tonnes.

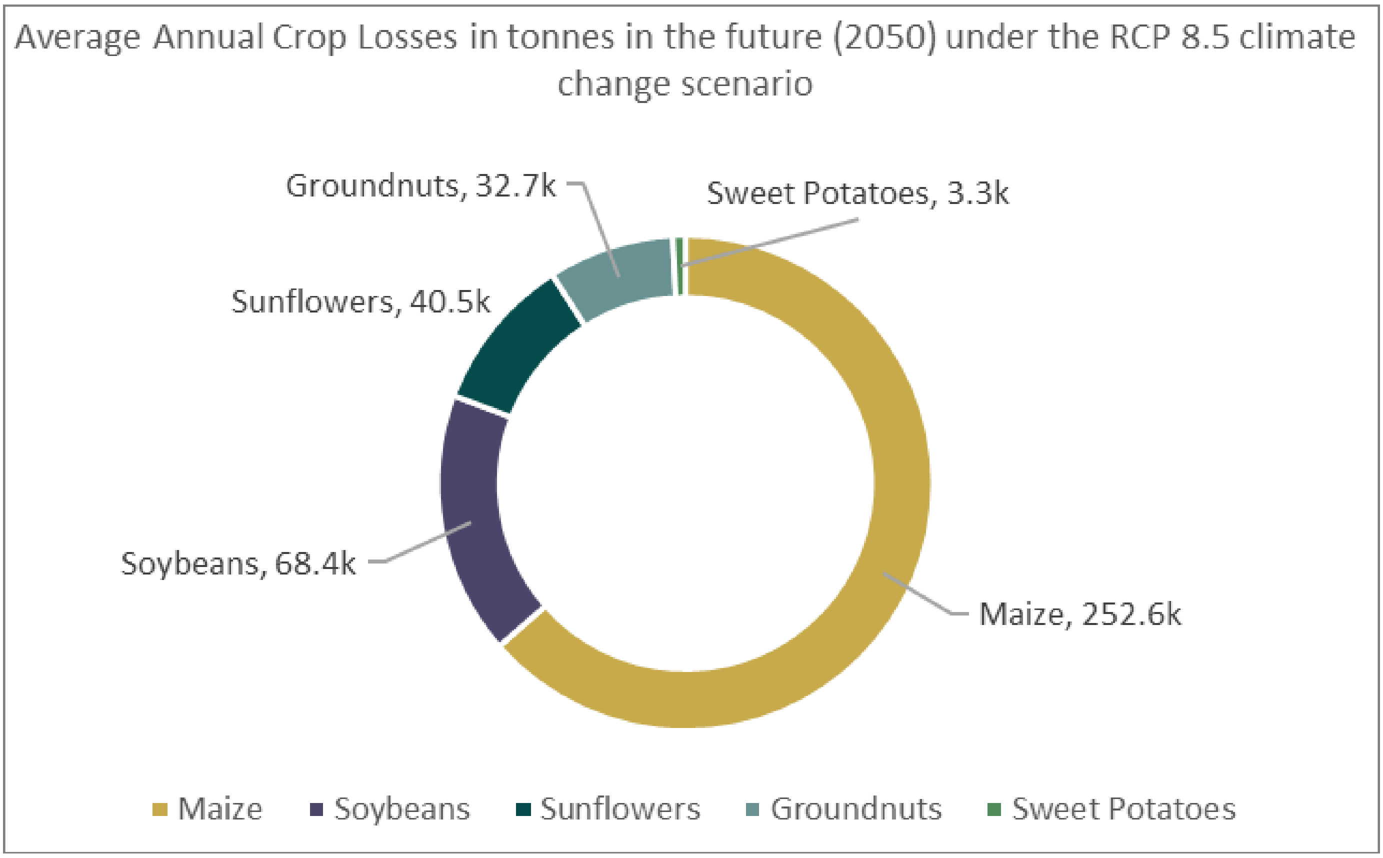


Figure 3: Average Annual Future Crop Losses in the Eastern Province (RCP 8.5).

The total annual expected monetary losses are projected to be up to USD 74 million per year due to climate change for crops under the severe climate change scenario in 2050, with USD 47 million for maize, followed by USD 25 million for soybeans.

MAIZE

Drought has a significant impact on maize production in Zambia, where maize is the primary staple crop and is predominantly cultivated by smallholder farmers who heavily rely on rainfall for their livelihoods.

Maize production plays a central role in both the country's economy and the food security of households. Climate change is expected to exacerbate existing production losses due to droughts, including the El Niño phenomenon, and increase interannual variability in harvests. Particularly through changes in temperature and precipitation patterns, more frequent and prolonged droughts pose a significant risk to maize production by increasing the frequency and duration of dry spells during critical growth stages and intensifying heat stress, which directly reduces yields and increases the likelihood of crop failure. (Siatwiinda et al. 2021)

The results of the CLIMADA-driven current and future risk analyses indicate that maize production losses due to drought are already significant and are projected to increase by 2050 under a high-emissions climate scenario (RCP8.5). The spatial analysis of drought-related maize production losses in Figure 4 highlights both the current and projected impacts. The maps display the average expected production losses of maize at a 20 km² resolution, highlighting hotspots in districts such as Chipata and Lundazi. Under the future climate scenario (RCP 8.5, 2050), the maps indicate an expansion and intensification of maize production losses across the province, affecting mainly the eastern districts. Areas currently experiencing moderate risk are shifting towards substantially higher levels of affected maize production losses in the future, with many new risk hotspots coming up across much of the province.

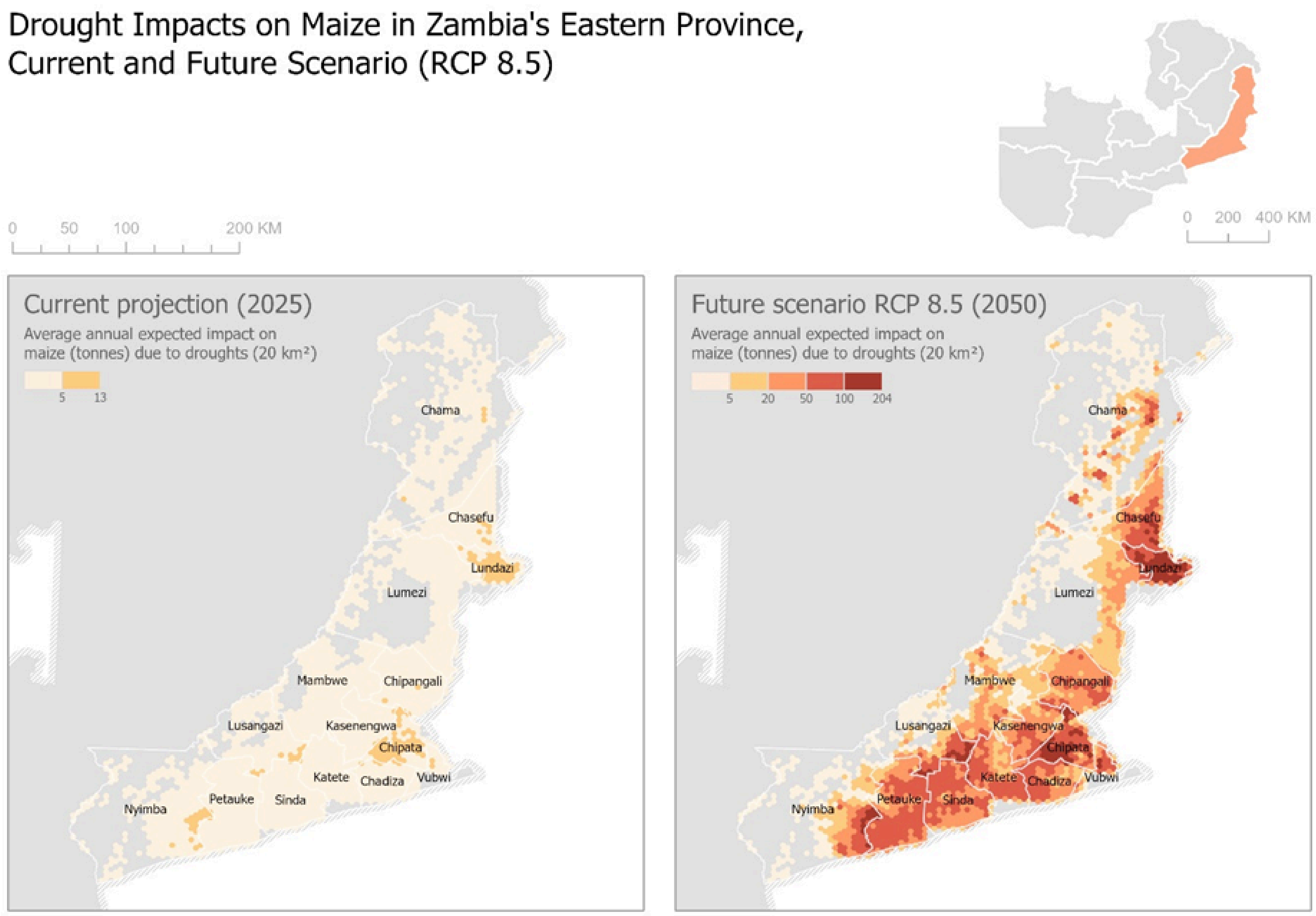
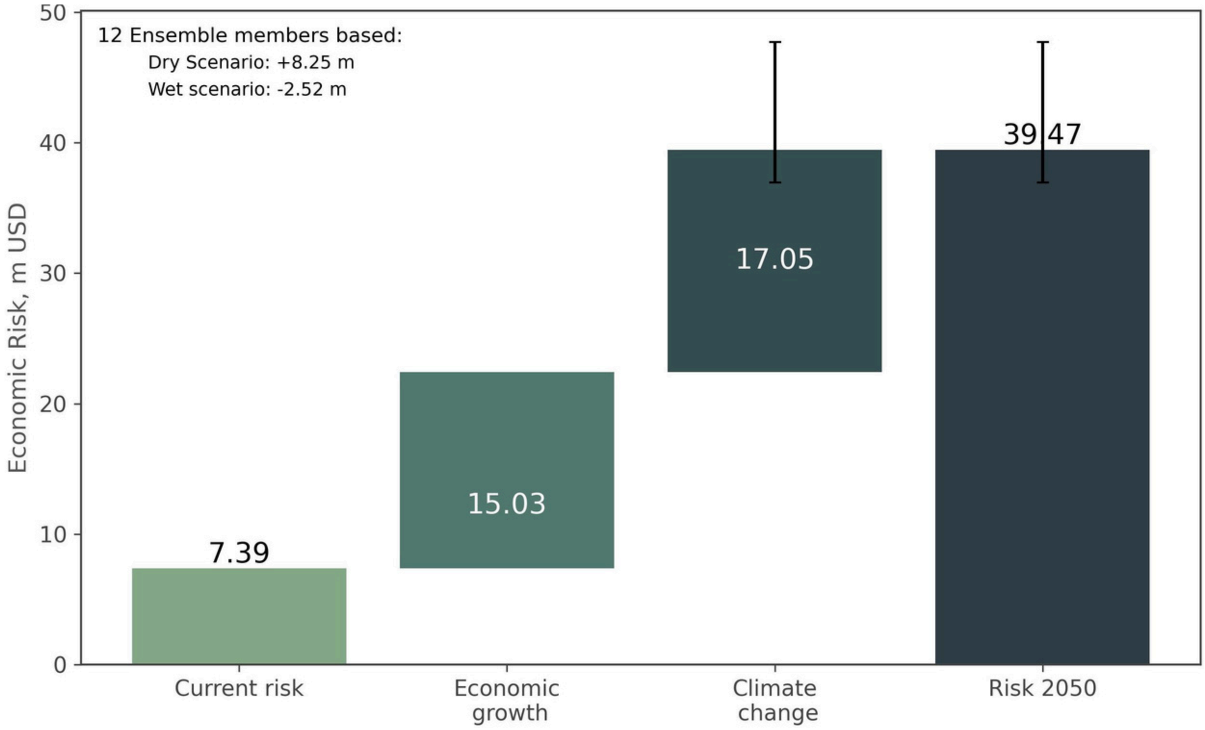


Figure 4: Drought impacts on maize production for current and future (2050, RCP 8.5) scenarios.

The production losses of maize also translate into direct monetary losses for the province and the country. Economic growth and climate change together increase the economic losses of maize, with climate change emerging as the dominant driver of increased risk in future projections, particularly under the RCP 8.5 scenario. As Figure 5 indicates, on average, USD 7.4 million of maize is lost due to droughts every year under the current scenario. This value represents the average of all years, regardless of whether a no drought, a mild drought, or a severe drought was registered. While production losses can have various reasons, such as pest infestations or floods, these numbers specifically refer to drought-induced maize losses. The whiskers indicate further uncertainties in climate change resulting from the incorporation of different drought scenarios in the calculation.

By 2050, due to economic growth, an additional USD 15 million in maize losses are projected to occur on average each year. Including climate change in the model, the results show that for the moderate climate change scenario (RCP 4.5), an additional USD 17 million of maize will be lost on average due to droughts every year. Together with the estimated economic growth and current risk, over USD 39 million is projected to be lost annually due to droughts under the moderate climate change scenario for maize only. For the severe climate change scenario (RCP 8.5), these numbers translate to approximately USD 46 million in monetary maize losses due to drought each year. The increase in the total number is due to the increased impacts of climate change, like heat and longer dry spells under the severe climate change scenario, on maize during drought.



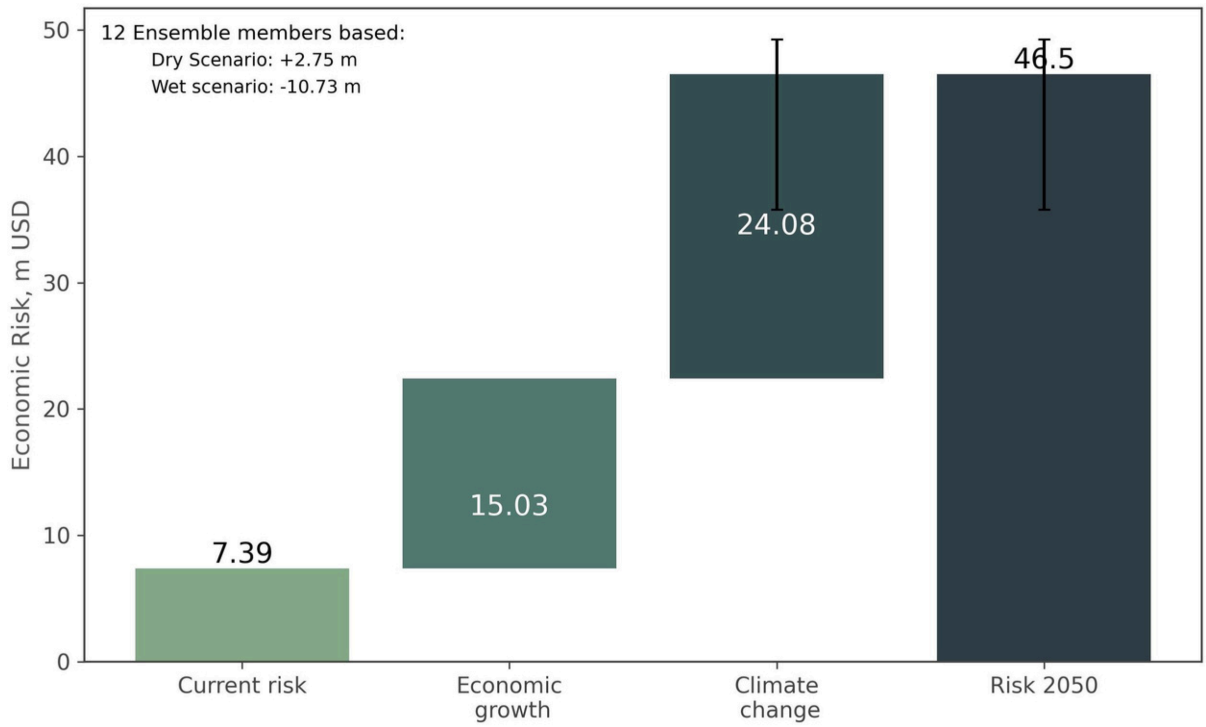


Figure 5: Average annual maize losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, these findings highlight maize as a high-risk crop within Zambia's agricultural sector, where drought risks are already substantial and are expected to intensify significantly under future climate change scenarios. Without targeted adaptation measures—such as drought- and heat-tolerant maize varieties, climate-smart agriculture, and diversification of cropping systems—drought-induced maize losses are likely to continue undermining both the livelihoods of smallholder farmers and the Zambian economy.

GROUNDNUTS

Drought has a significant impact on groundnut production in Zambia, where groundnuts are among the most important crops for smallholder farmers, providing both food and income.

Groundnuts play a crucial role in household nutrition as a key source of protein, which contributes to the prevention of malnutrition (Pokhrel et al. 2024). Since groundnuts are widely regarded as a "women's crop", climate-induced production shocks disproportionately affect women's livelihoods and food security. (Mphande et al. 2022) Climate change is expected to intensify drought-related risks to groundnut production through changes in temperature and precipitation patterns. More frequent and prolonged droughts increase water stress, leading to substantial production losses and declines in crop quality. Drought stress has been shown to severely reduce groundnut pod yields and to impair nutrient uptake, thereby affecting plant growth, biomass accumulation, and seed development. Beyond production losses, drought conditions also increase the risk of pre-harvest aflatoxin contamination, posing serious threats to human and animal health. (Pokhrel et al. 2024)

The results of the CLIMADA-driven current and future risk analyses indicate that drought-induced groundnut production losses are already significant and are projected to increase by 2050 under a high-emissions climate scenario (RCP 8.5). The spatial analysis of drought-related groundnut production losses, as shown in Figure 6, highlights both current and future impacts. The maps display the average expected production losses of groundnuts at a 20 km^2 resolution, revealing existing hotspots and showing a clear intensification and spatial expansion of losses under future climate conditions, with high-risk districts including Chasefu, Chipata, and Chipangali. Overall, all groundnut-producing areas are projected to experience significant drought-related losses in the future due to climate change.

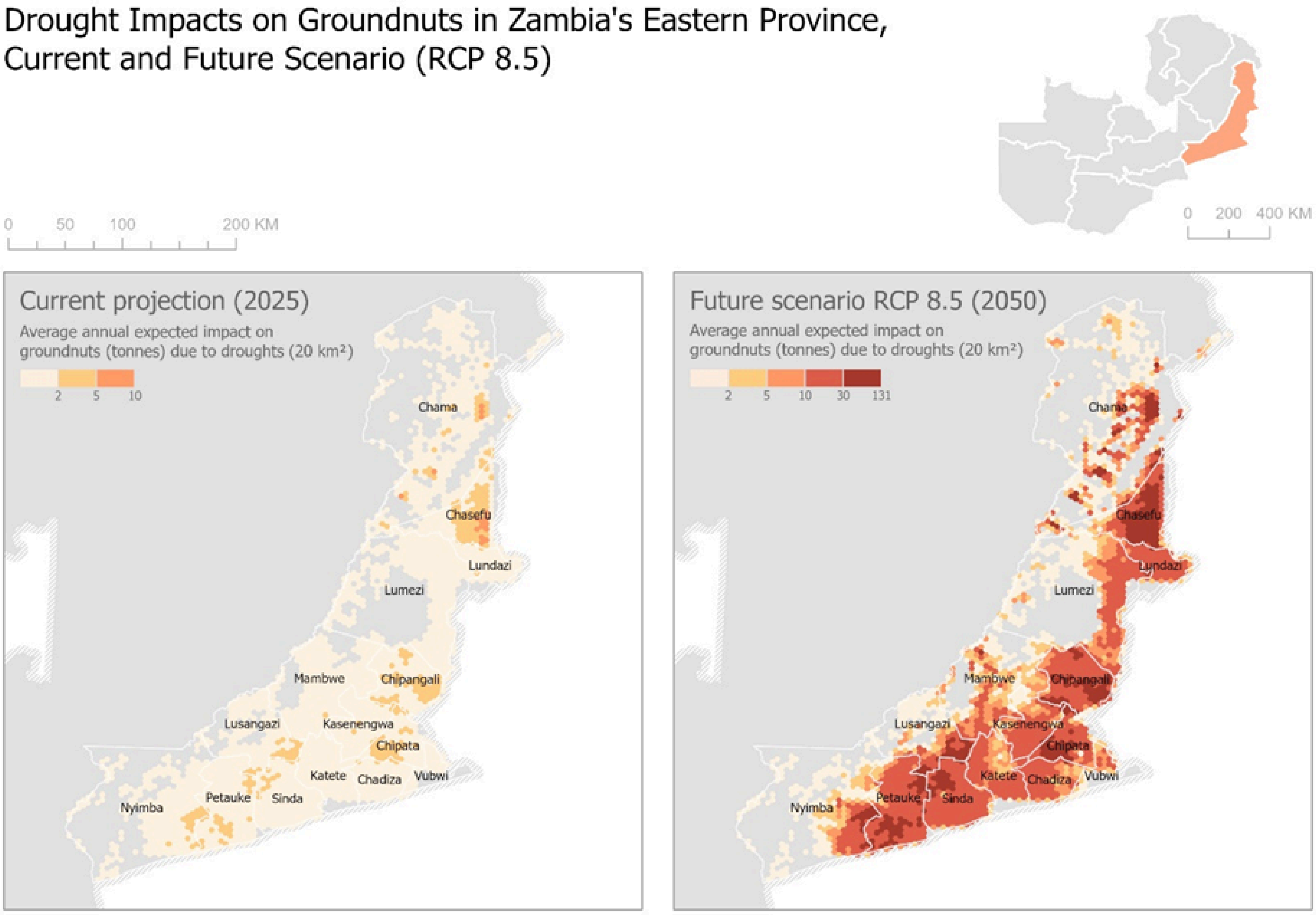
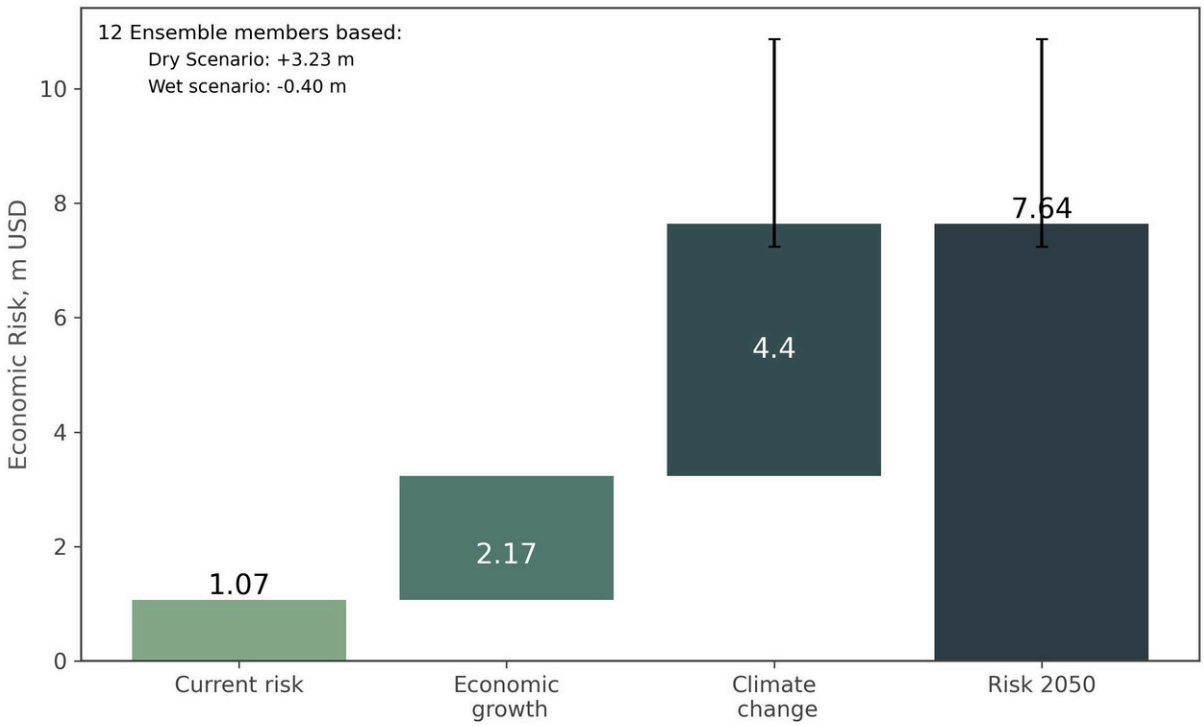


Figure 6: Drought impacts on groundnut production for current and future (2050, RCP 8.5) scenarios.

Groundnut production losses also result in direct monetary losses for the province. Economic growth and climate change together increase the expected economic losses associated with drought impacts on groundnuts, with climate change emerging as the dominant driver of increased risk in future projections, particularly under the RCP 8.5 scenario. As shown in Figure 7, average annual groundnut losses due to drought are estimated at approximately USD 1.1 million under current conditions. By 2050, economic growth alone is projected to increase average annual losses by an additional USD 2.2 million. When climate change impacts are included, average annual drought-induced losses are projected to rise to USD 7.6 million under a moderate climate change scenario (RCP 4.5) and to approximately USD 10 million under a severe climate change scenario (RCP 8.5). The higher losses under the severe scenario reflect the compounded effects of increased heat stress and longer dry spells on groundnut yields and quality.



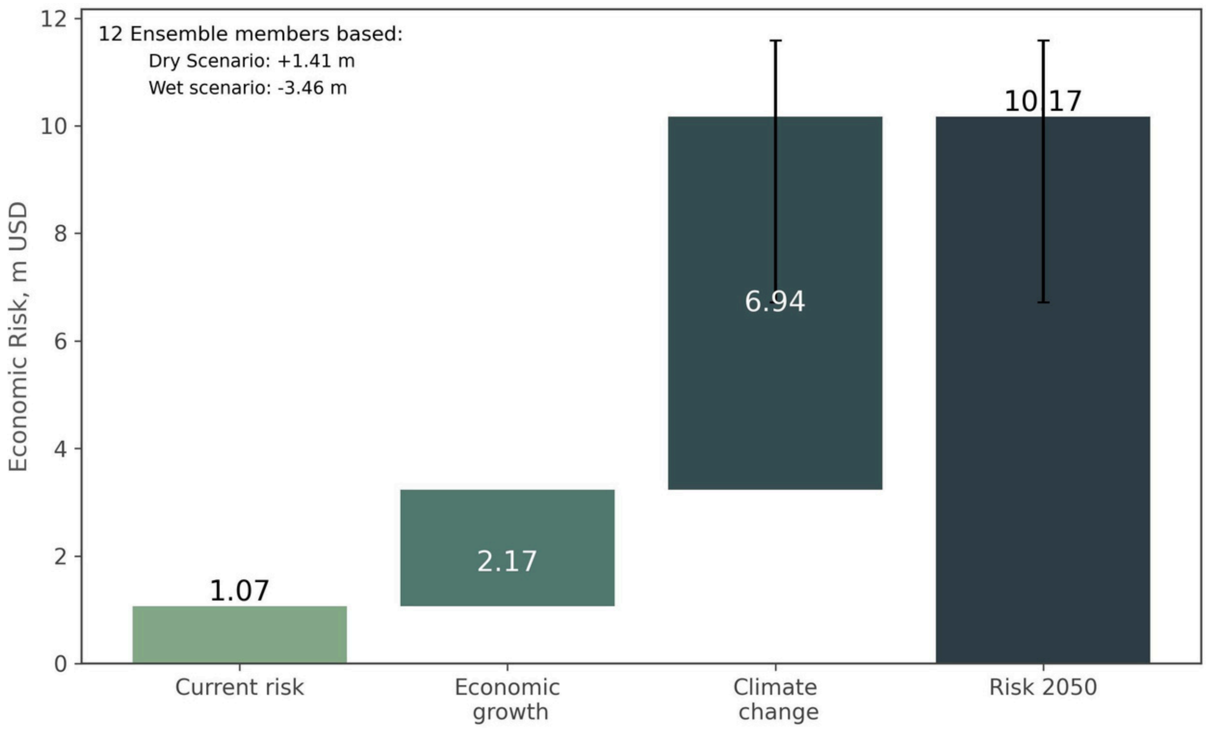


Figure 7: Average annual groundnut losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, these findings identify groundnuts as a climate-sensitive and socioeconomically critical crop within Zambia's agricultural system. Given their importance for income generation, household nutrition, and women's livelihoods, increasing drought risks to groundnut production underscore the need for targeted adaptation measures, including drought-resilient legume varieties, improved soil and water management, and gender-responsive climate-smart agriculture interventions. Without such measures, the rising impacts of drought on groundnuts are likely to further undermine food security, nutrition outcomes, and the economic resilience of smallholder farming households.

SOYBEANS

Drought and climate variability are increasingly affecting soybean production in Zambia, where soybeans have become an important crop for smallholder farmers due to their role in food, feed, and income generation.

Soybeans serve as a key source of protein in human diets and are utilized in the production of edible oils and animal feed. Over the past decade, smallholder farmers have significantly increased their soybean production in Zambia (Mphande et al. 2022). This trend reflects the growing importance of soybeans as a diversification crop within Zambia's agricultural sector and as a source of income. Soybean adoption plays a crucial role in enhancing food security while also generating broader socioeconomic benefits, including strengthened trade. Climate change adaptation measures in soybean cultivation significantly increase the probability of improved rural livelihoods for small-scale farmers. For smallholder producers, soybeans are comparatively easy to cultivate and have a shorter growing season than many traditional crops, which reduces production risks under variable climatic conditions. These characteristics make soybeans particularly attractive to national governments and development partners seeking scalable, climate-resilient agricultural options. (Siamabele and Manda 2024).

The results of the CLIMADA-driven current and future risk analyses indicate that drought-induced soybean production losses are already present and are projected to increase by 2050 under a high-emissions climate scenario (RCP 8.5). The spatial analysis of drought-related soybean production losses in Figure 8 presents both current and future patterns of risk. The maps show the average expected production losses of soybeans at a 20 km² resolution, revealing existing areas of elevated risk and a clear expansion and intensification of losses under future climate conditions. Areas currently experiencing moderate production losses are projected to transition towards substantially higher risk levels, with additional hotspots emerging across the province by mid-century.

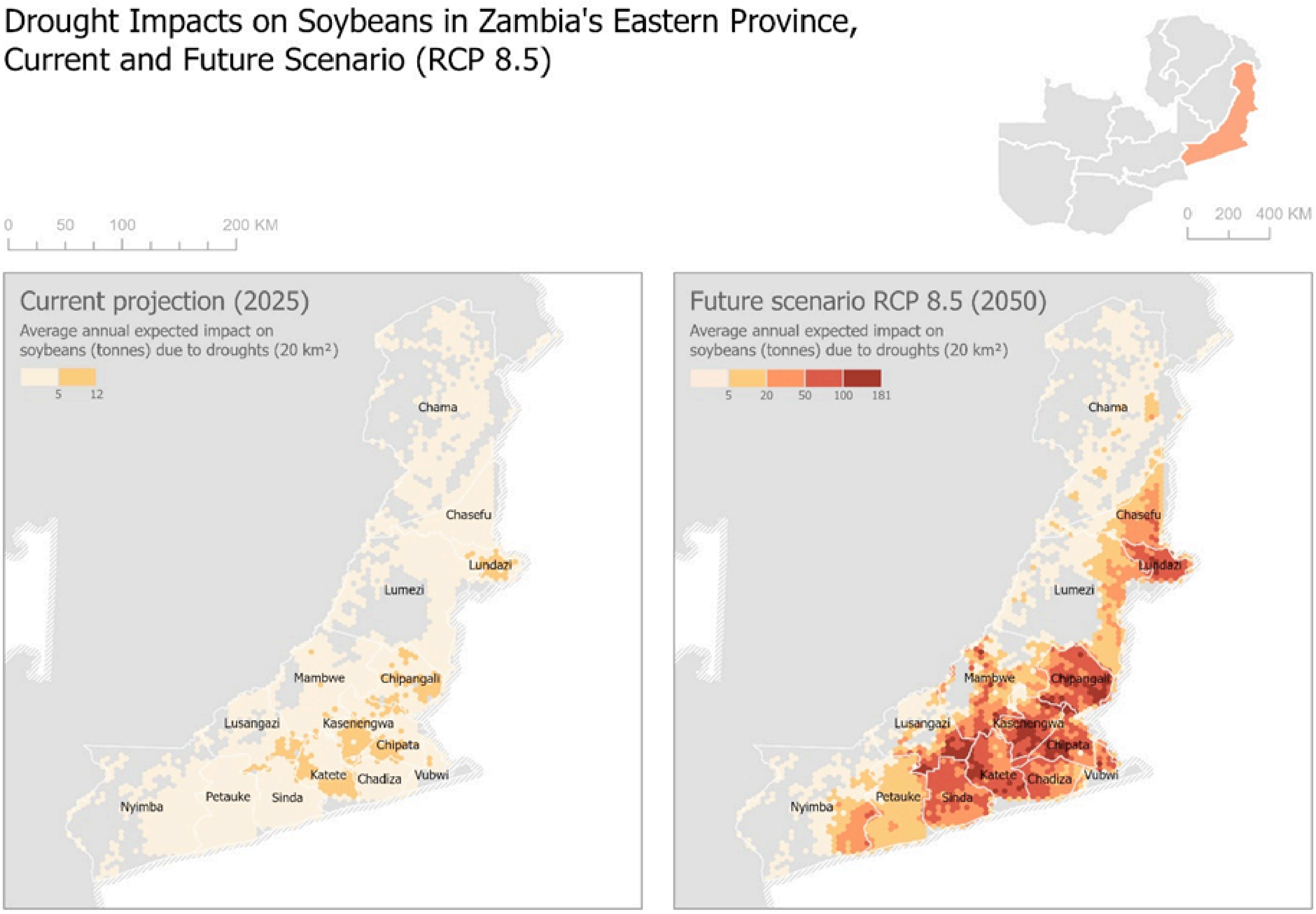
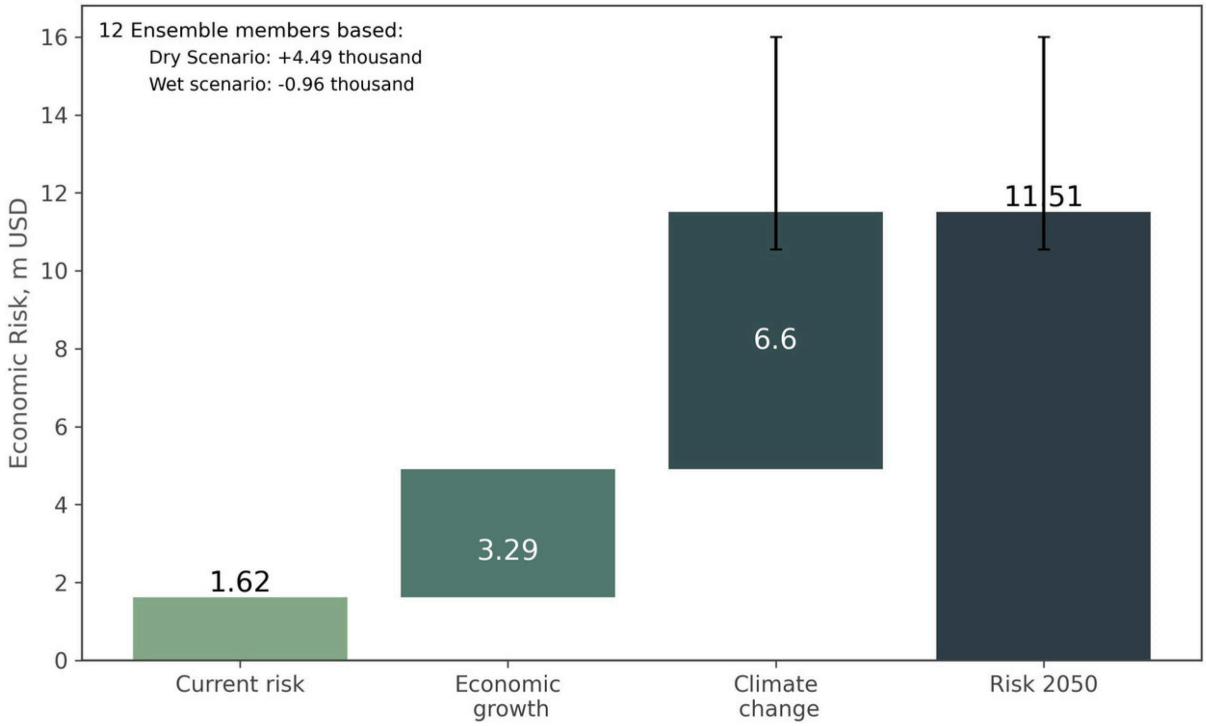


Figure 8: Drought impacts on soybean production for current and future (2050, RCP 8.5) scenarios.

These production losses result in direct economic impacts for farmers and the broader agricultural sector. Economic growth and climate change jointly contribute to rising monetary losses from drought-related impacts on soybean production, with climate change emerging as the dominant driver of future risk, particularly under the RCP 8.5 scenario. As shown in Figure 9, average annual soybean losses due to drought are estimated at approximately USD 1.6 million under current conditions. By 2050, economic growth alone is projected to increase these losses by an additional USD 3.3 million per year. Climate change alone contributes USD 6.6 million in the RCP 4.5 scenario and up to USD 10 million in the RCP 8.5 scenario. When climate change and economic impacts are included, average annual drought-induced soybean losses are projected to reach USD 12 million under a moderate climate change scenario (RCP 4.5) and approximately USD 15 million under a severe climate change scenario (RCP 8.5).



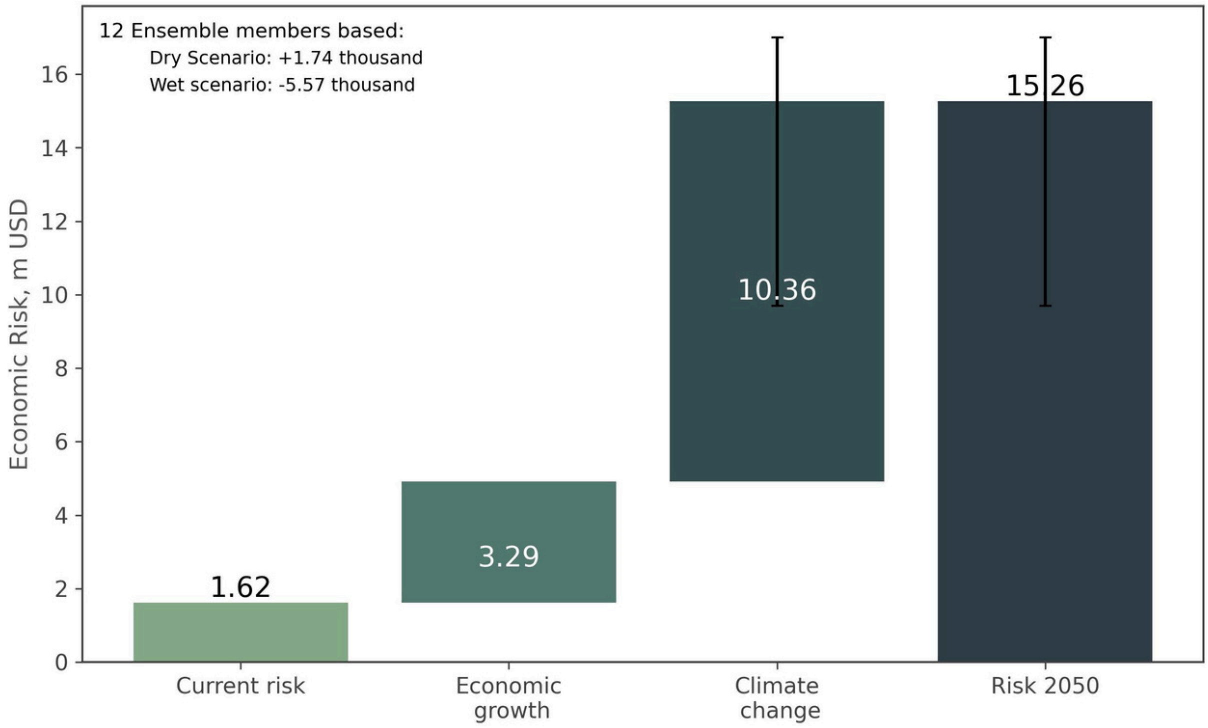


Figure 9: Average annual soybean losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, these findings suggest that while soybeans offer significant opportunities for income diversification, enhancing soil fertility, and improving nutrition, their production is increasingly vulnerable to drought risks under climate change. Strengthening the resilience of soybean production systems through drought-tolerant varieties, climate-smart agricultural practices, and targeted support to smallholder farmers will be critical to sustaining the role of soybeans in supporting food security, livelihoods, and sustainable agricultural development in Zambia.

SUNFLOWERS

Drought is increasingly affecting sunflower production in Zambia, impacting sunflower oil production and having economic consequences at both household and provincial levels.

In addition to oil production, sunflower meal and whole kernels provide a valuable source of protein for human food formulations and animal feed, strengthening their role in food and nutritional security. Sunflowers are moderately drought-tolerant, largely due to their extensive root systems. This allows sunflowers to maintain relatively stable yields under moderate water stress compared to shallow-rooted crops. However, sunflower productivity remains sensitive to drought and heat stress during critical phenological stages, particularly flowering and grain filling. Under water-limited conditions, drought, high temperatures, and low humidity disrupt nutrient uptake, photosynthesis, and overall plant development, leading to reductions in seed yield and oil quality when stress is prolonged or severe. (Phiri and Zimba 2018).

The CLIMADA-driven drought risk analysis indicates where areas of high risk of drought-related production losses for sunflowers are located today and in the future (2050), see Figure 10. While losses are generally lower than those observed for highly drought-sensitive staple crops, the spatial analysis reveals localized hotspots where sunflower production is particularly exposed. High-risk districts are mostly located in the south of the eastern province, as well as in Chasefu and Lundazi in the northern part. Under future climate conditions, CLIMADA projections show an increase in drought-related risks to sunflower production by 2050 under a high-emissions climate scenario (RCP 8.5). The spatial analysis suggests a moderate intensification and geographic expansion of production losses. Although sunflowers' deep-root system provides some buffering capacity, higher temperatures and longer dry spells under future climate scenarios are projected to exacerbate production losses.

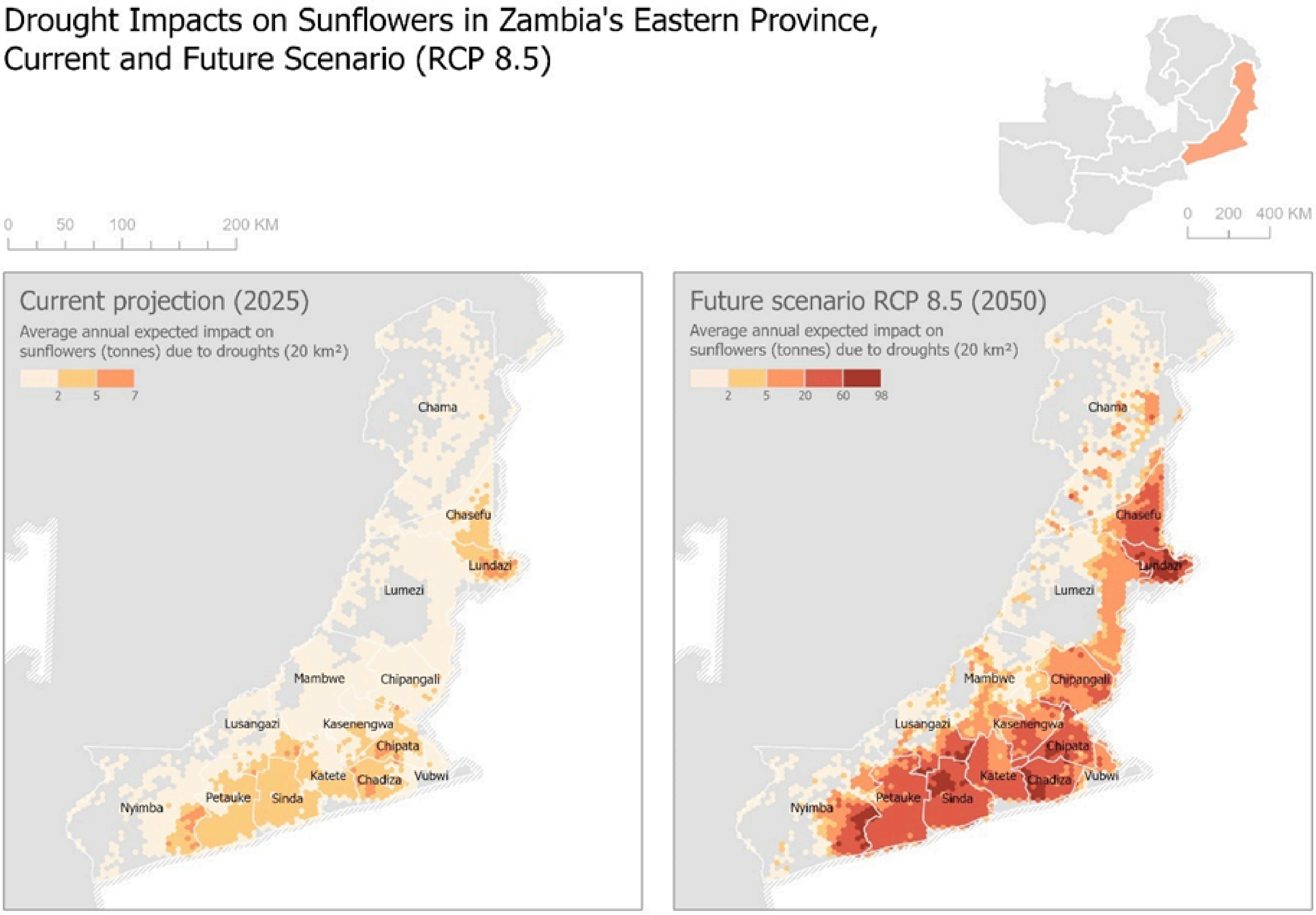
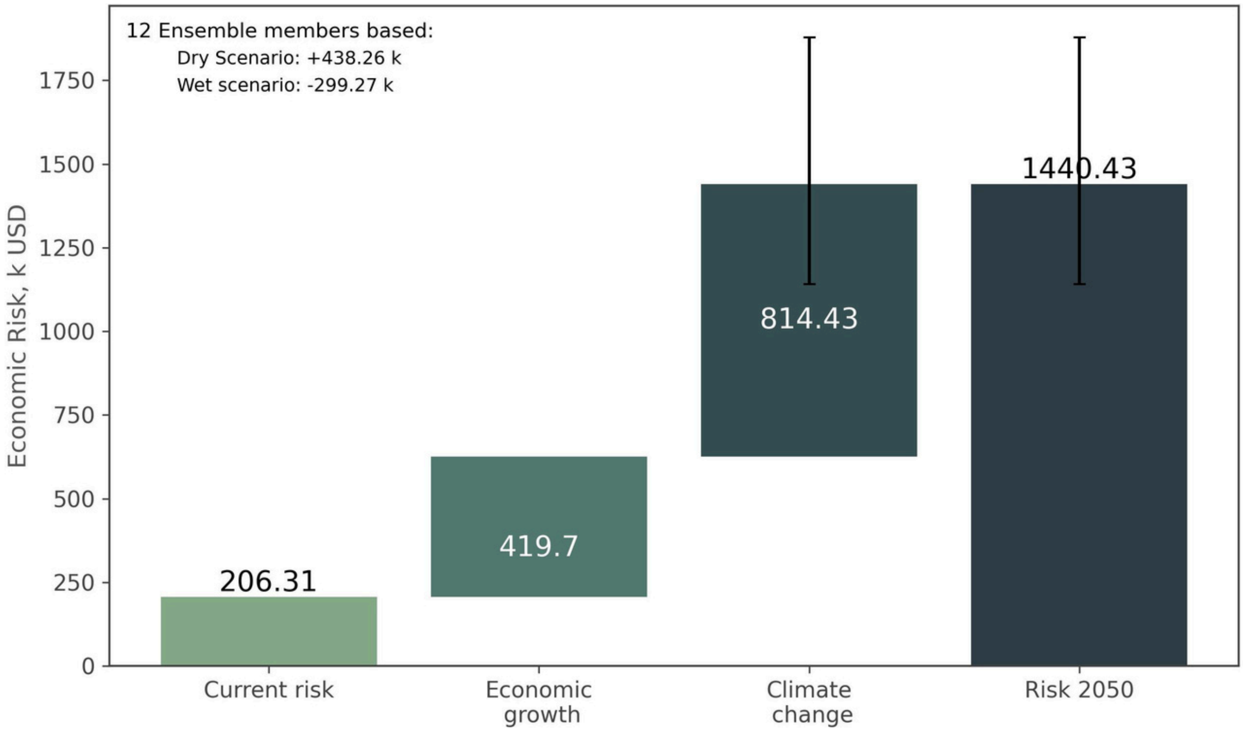


Figure 10: Drought impacts on sunflower production for current and future (2050, RCP 8.5) scenarios.

These production losses result in direct economic impacts for sunflower producers and the broader agricultural sector. Both economic growth and climate change contribute to increasing monetary losses from drought-related impacts on sunflower production, with climate change emerging as the primary driver of future risk, particularly under the high-emissions scenario (RCP 8.5). As illustrated in Figure 11, average annual sunflower losses due to drought are estimated at approximately USD 206,000 under current conditions. By 2050, economic growth alone is projected to increase these losses by an additional USD 420,000 per year. Climate change is expected to further amplify losses, contributing an estimated USD 814,000 under a moderate climate change scenario (RCP 4.5) and up to USD 1.2 million under a severe climate change scenario (RCP 8.5). When both economic growth and climate change effects are considered together, average annual drought-induced losses in sunflower production are projected to reach around USD 1.4 million under RCP 4.5 and approximately USD 1.8 million under RCP 8.5.



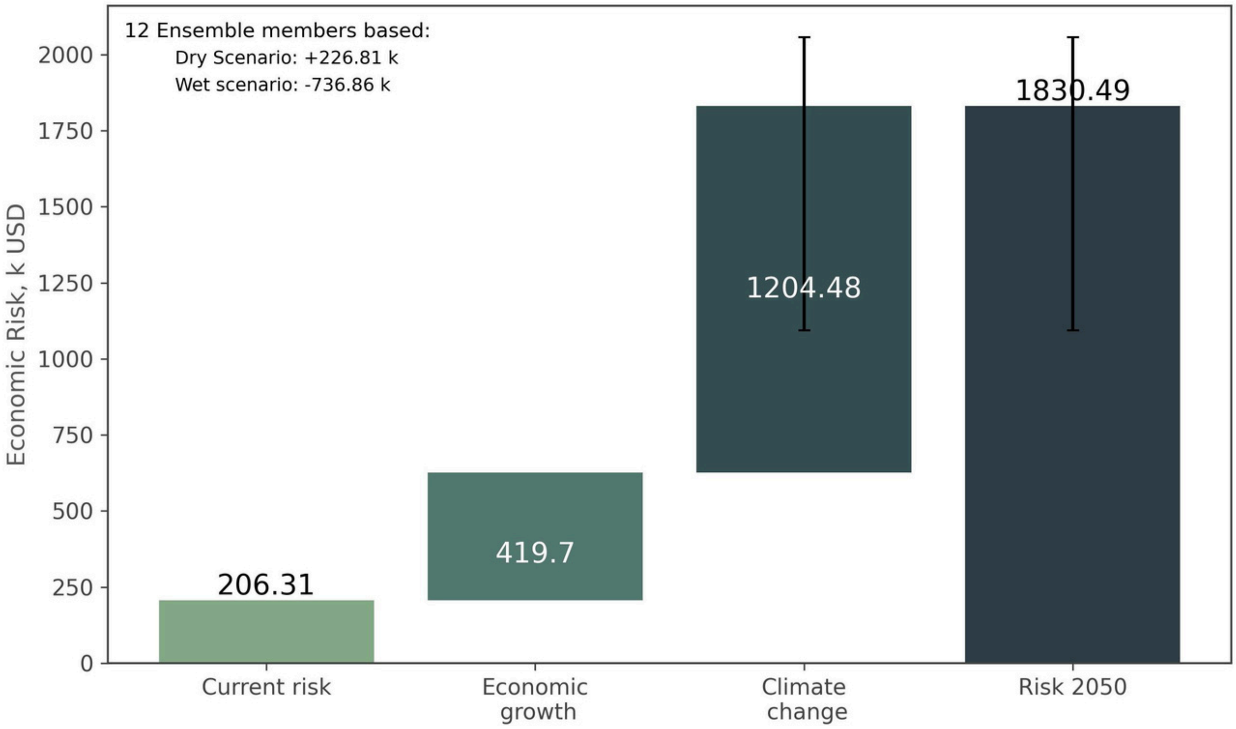


Figure 11: Average annual sunflower losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, the CLIMADA-based risk assessment positions sunflower as a moderately climate-resilient oilseed crop with growing relevance in the context of climate variability and change. While sunflowers can perform reasonably well under moderate drought stress, increasing climate extremes are expected to elevate production risks in the absence of targeted adaptation measures. Strengthening sunflower resilience through drought- and heat-tolerant varieties, improved soil and water management, and supporting farmers can help safeguard production and the crop's contribution to income diversification and agro-industrial development in Zambia.

SWEET POTATOES

Drought affects sweet potato production in Zambia, although the crop is generally considered more drought-tolerant than many other staple crops.

Sweet potatoes are a key indigenous root crop widely grown by smallholder farmers, valued for their versatility, resilience, and significant contribution to household food security. They are highly nutrient-dense, surpassing most staple crops in vitamins, minerals, dietary fiber, and protein, and therefore play an important role in supporting both caloric intake and nutritional quality. During droughts, from a biophysical perspective, drought reduces available soil moisture and disrupts the water balance of sweet potato plants, leading to smaller leaf development and restricted canopy growth. This limits photosynthetic capacity and reduces the biomass available for storage root formation, resulting in lower yields under drought conditions. (Motsa et al. 2015).

The maps in Figure 12 show a moderate expansion and intensification of production losses in areas already exposed to drought stress, although the magnitude of projected losses remains lower compared to other assessed crops. This reflects the crop's prolific root system and high phenotypic plasticity as a C3 plant, which enables sweet potatoes to more effectively access soil moisture and adjust their growth under water-limited conditions (Motsa et al. 2015). The spatial analysis of drought-related sweet potato production losses shows that production reductions remain strongly dependent on local conditions, with variability across districts, with the most affected districts being Chasefu, Chipangali, and Chadiza. Under future climate conditions, the CLIMADA projections indicate an increase in drought-related risks to sweet potato production by 2050. This suggests that while sweet potatoes offer a degree of buffering capacity against increasing droughts, they are not immune to the impacts of climate change, particularly under prolonged dry spells and higher temperatures.

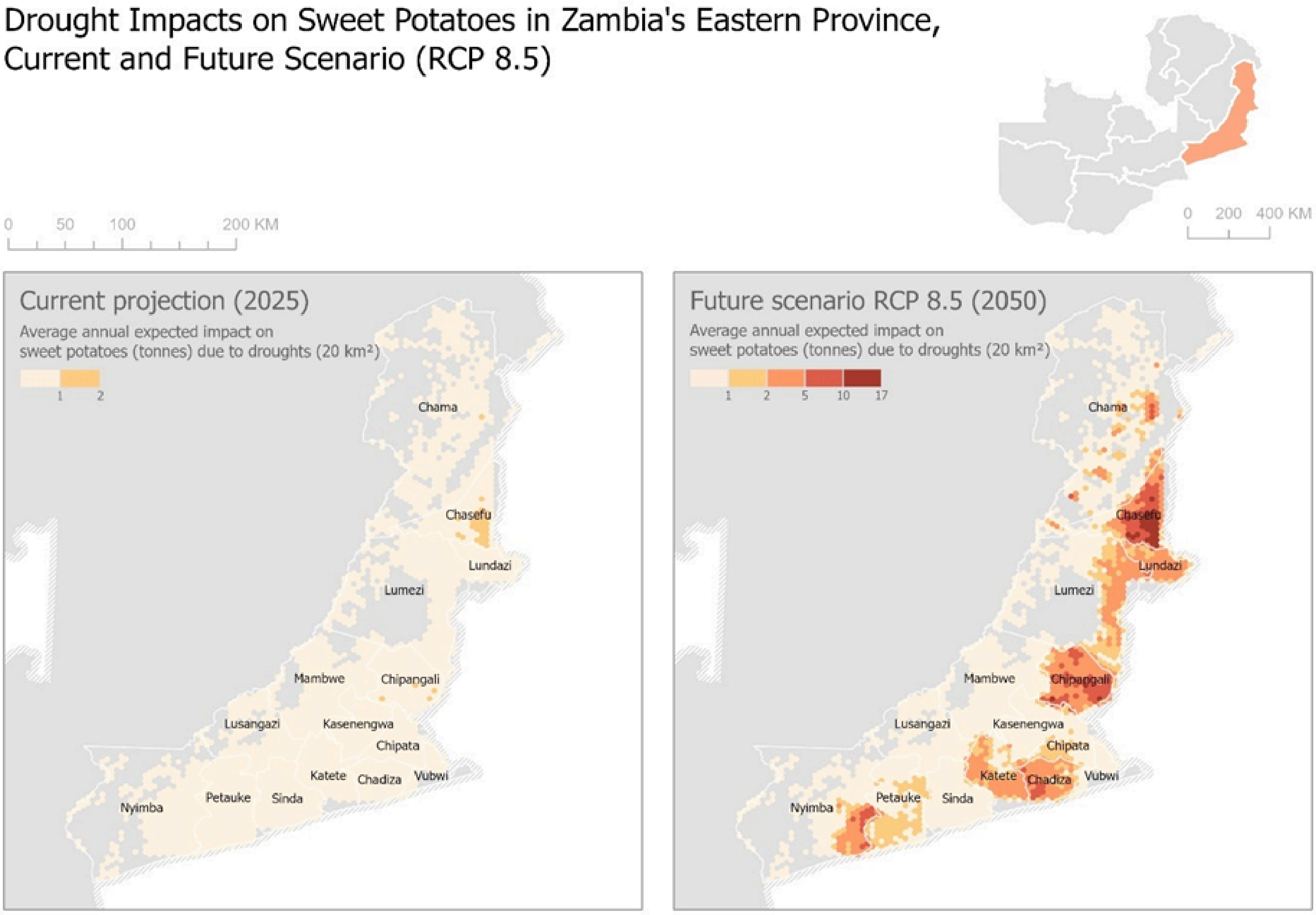


Figure 12: Drought impacts on sweet potato production for current and future (2050, RCP 8.5) scenarios.

These production losses result in direct economic impacts, where economic growth and climate change contribute to rising monetary losses from drought-related impacts on sweet potato production. Climate change emerges as the dominant driver of future risk, particularly under the RCP 8.5 scenario. As shown in Figure 13, average annual sweet potato losses due to drought are estimated at approximately USD 30,000 under current conditions. By 2050, economic growth alone is projected to increase these losses by an additional USD 60,000 per year. Climate change is contributing USD 75,000 in the RCP 4.5 and up to USD 133,000 in the RCP 8.5 scenario. When climate change and economic impacts are included, average annual drought-induced soybean losses are projected to reach USD 165,000 under a moderate climate change scenario (RCP 4.5) and approximately USD 222,000 under a severe climate change scenario (RCP 8.5).

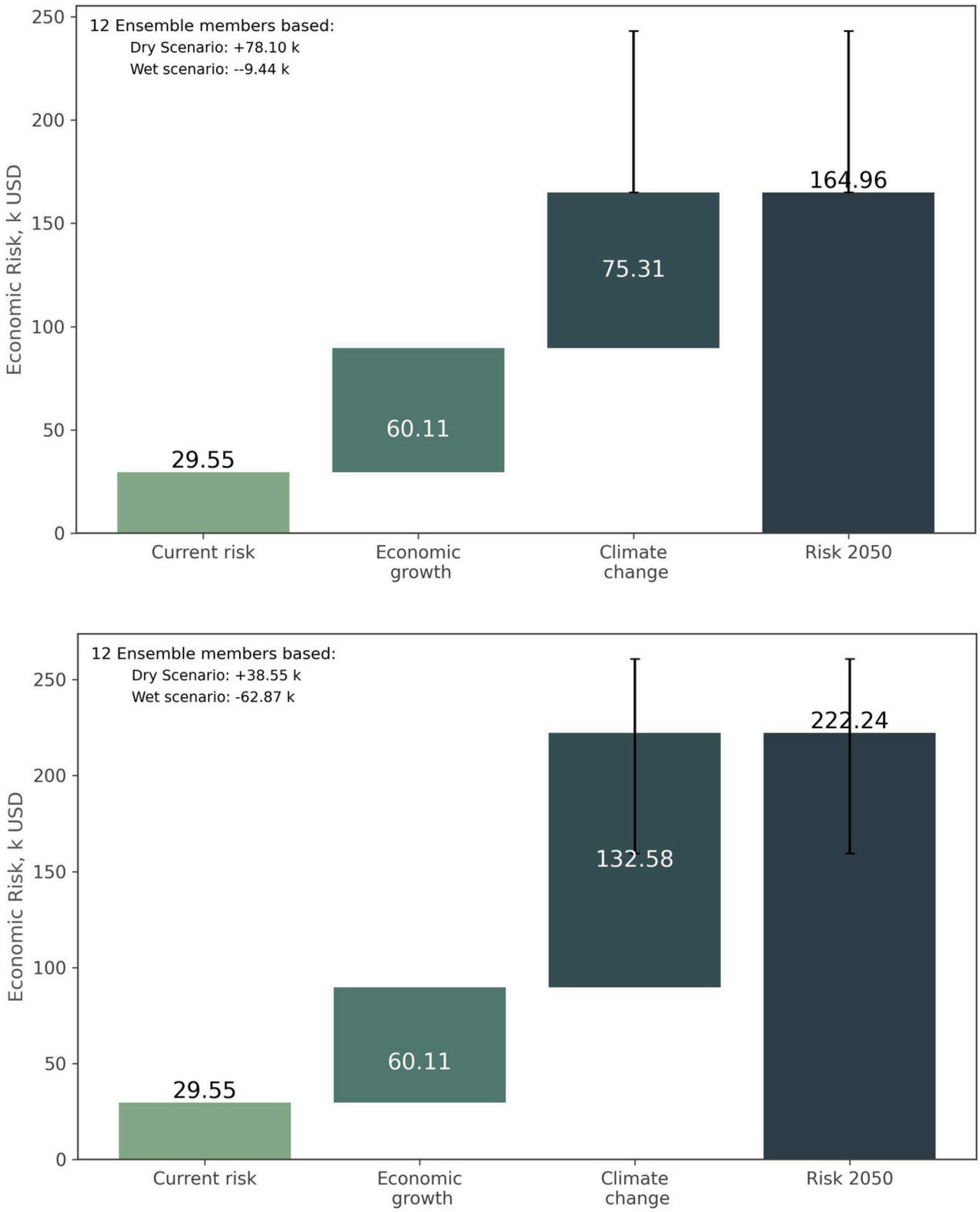


Figure 13: Average annual sweet potato losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, the CLIMADA-based risk assessment highlights sweet potatoes as a comparatively climate-resilient crop that can contribute to reducing agricultural vulnerability in the face of increasing drought risk. While production losses are projected to rise under future climate scenarios, their relative stability and high nutritional value position sweet potatoes as a strategic crop for climate-smart agriculture and food security. Targeted support for drought-tolerant varieties, climate-smart agricultural management, and context-specific practices can further strengthen the role of sweet potatoes in enhancing smallholder resilience to climate variability and change.

2.2.2 DROUGHT IMPACTS ON LIVESTOCK

Droughts are already impacting livestock numbers in Zambia today and are likely to continue doing so in the future, given the effects of climate change. Already today, in the Eastern Province, the average annual livestock losses due to droughts are estimated at 11,000 animals (cattle and pigs) every year.

By 2050, the average annual livestock losses under the severe climate change scenario (RCP 8.5) are estimated to amount to 154,000 heads lost. The largest portion of these losses would be the annual cattle losses, projected to amount to 88,000 heads, followed by pigs at 66,000 heads. Figure 14 illustrates the share of future livestock losses in heads of cattle and pigs.

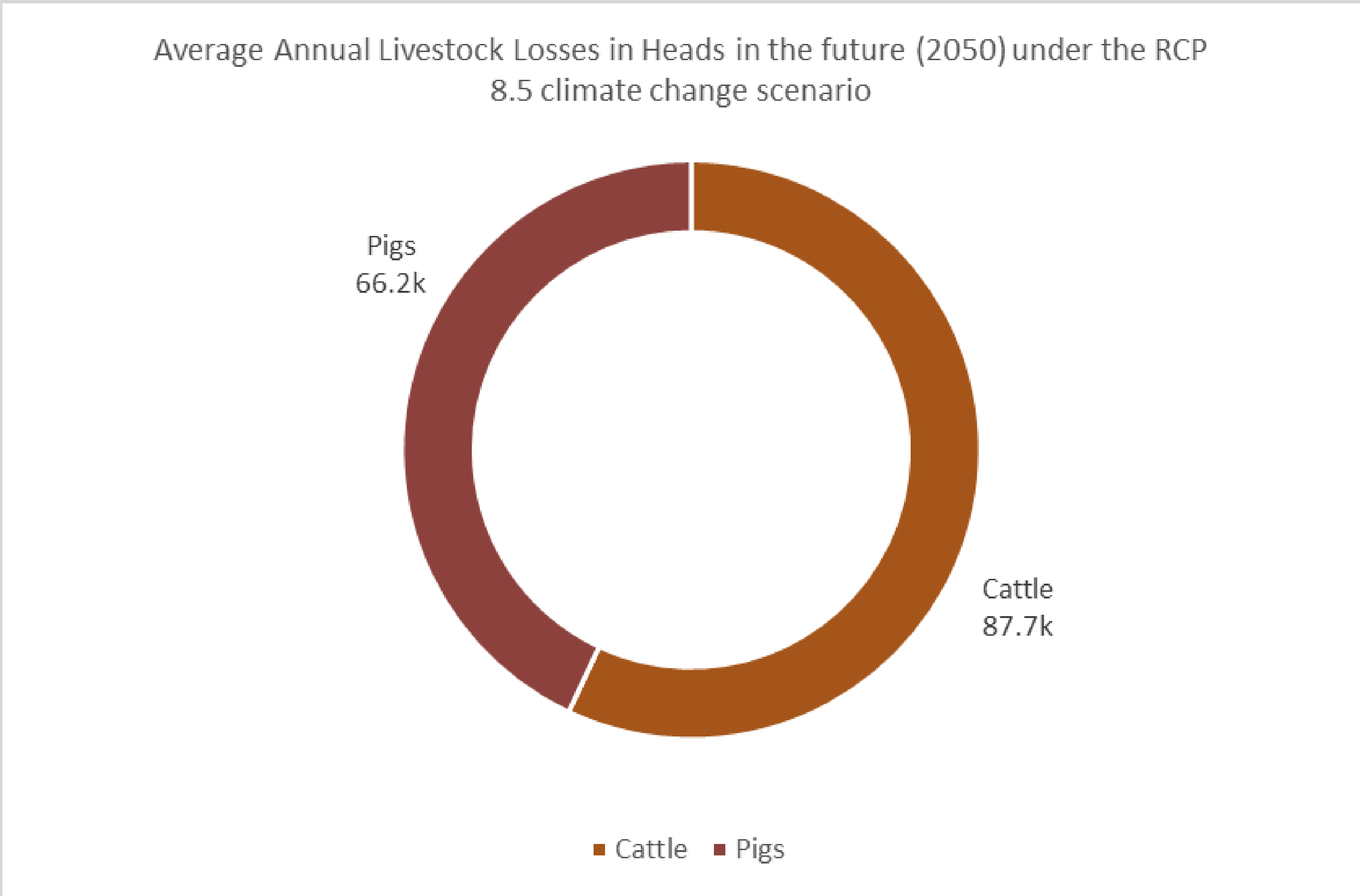


Figure 14: Average Annual Livestock Losses in Heads in the future (2050) under the RCP 8.5 climate change scenario.

The total annual expected monetary losses are projected to be up to USD 39 million per year due to climate change for livestock (cattle and pigs) under the severe climate change scenario in 2050, with USD 37 million for maize, followed by USD 2 million for pigs.

CATTLE

Drought is a major cause of cattle losses, primarily through acute water and feed shortages.

Drought is a major cause of cattle losses, primarily through acute water and feed shortages. Starvation linked to reduced forage availability is particularly affecting lactating and pregnant cows. Drought also indirectly increases cattle losses by exacerbating disease and parasite incidence. Overall, water scarcity, feed shortages, and heightened disease and parasite pressure are the key mechanisms through which drought leads to cattle losses, with their relative importance varying by agroecological and climate zone (Dzavo et al. 2019).

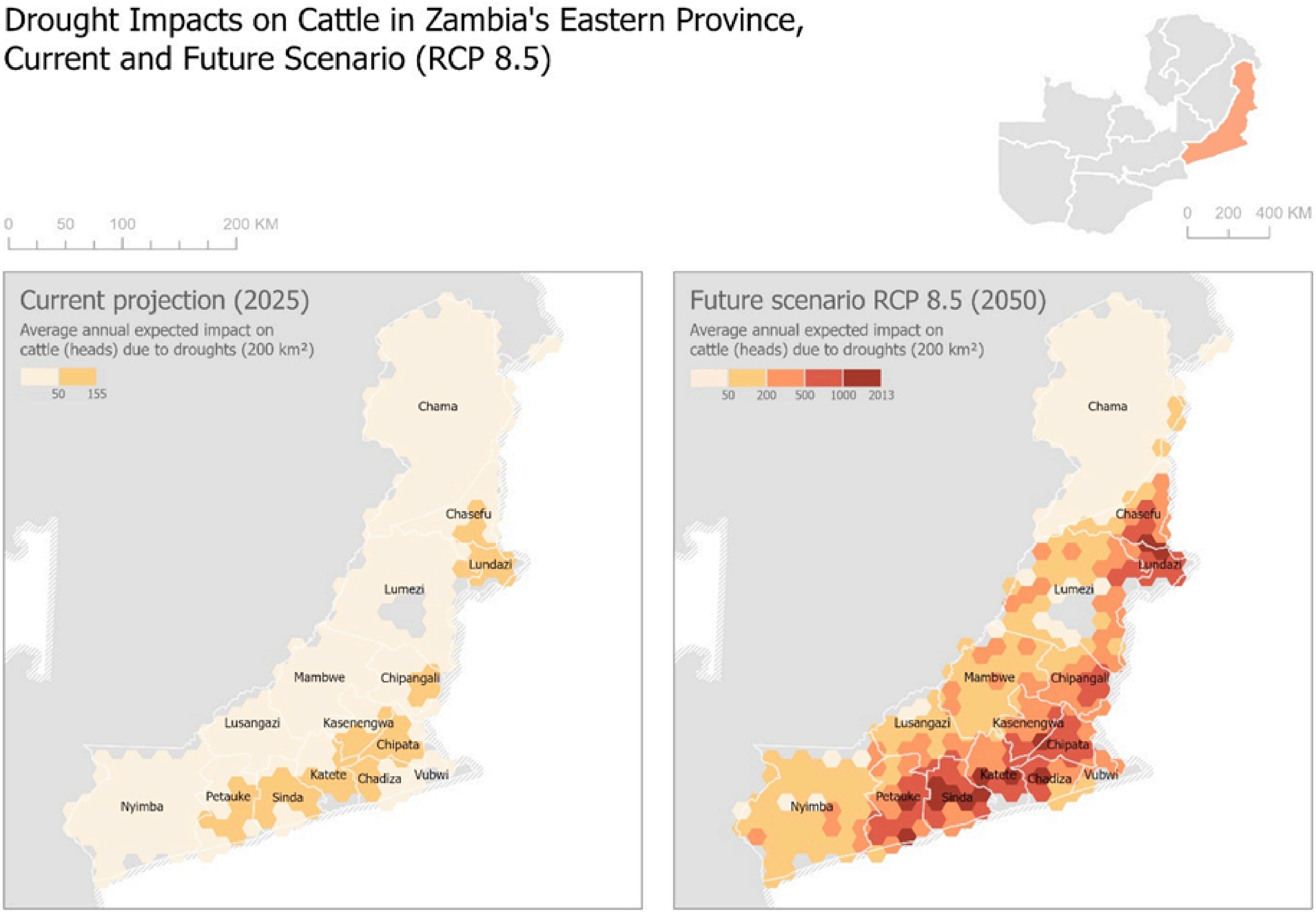
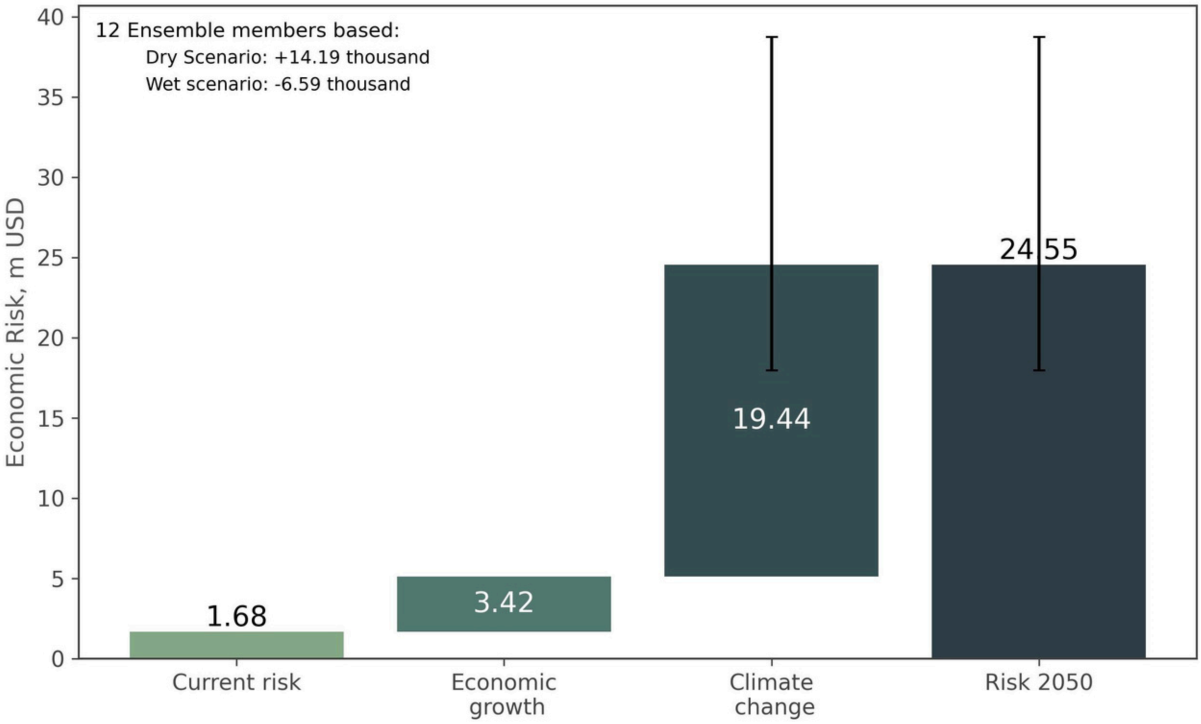


Figure 15: Drought impacts on cattle population for current and future (2050, RCP 8.5) scenarios.

Drought-related production losses in cattle result in significant economic impacts, driven by both climate change and projected economic growth. Under current conditions, average annual losses are estimated at approximately USD 1.7 million. By 2050, economic growth alone could increase these losses by an additional USD 3.4 million per year. Climate change further exacerbates the risk, contributing USD 19 million under a moderate scenario (RCP 4.5) and up to USD 31 million under a severe scenario (RCP 8.5). When combined, the total projected annual losses for cattle due to drought could reach USD 25 million under RCP 4.5 and approximately USD 36 million under RCP 8.5 (Figure 16).



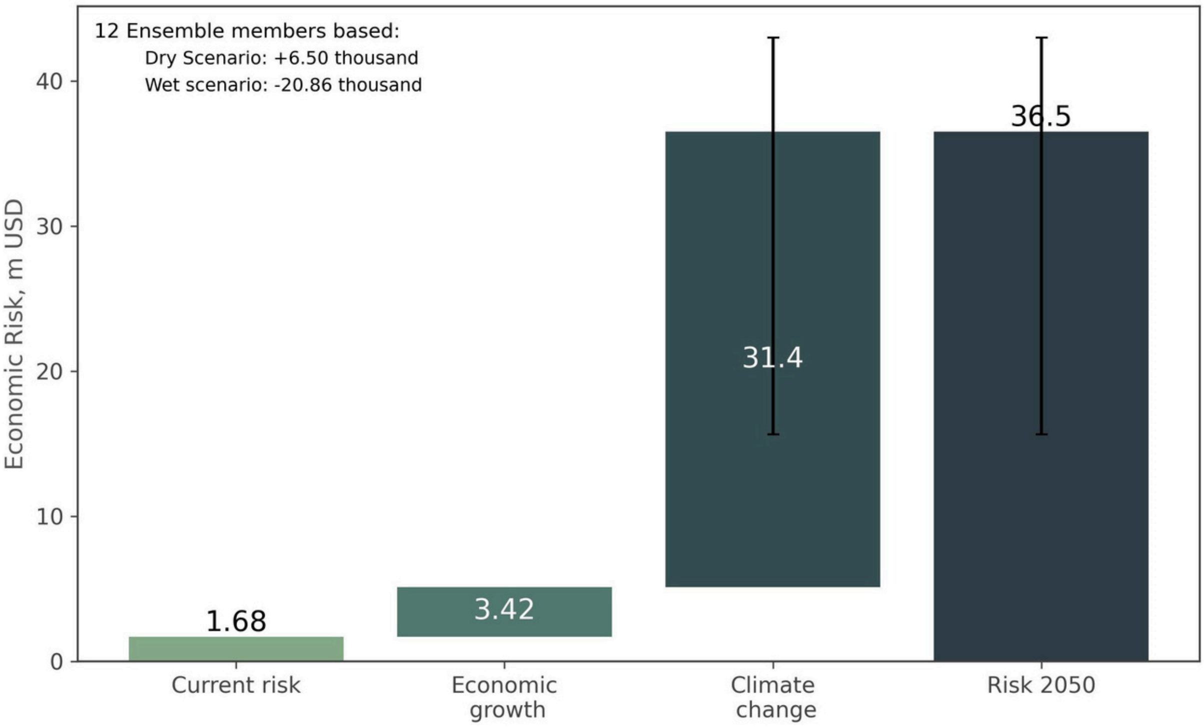


Figure 16: Average annual cattle losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, the findings highlight drought as a growing systemic risk to cattle production in Zambia's Eastern Province, with impacts that extend beyond direct cattle losses to substantial economic consequences. The projected intensification and spatial expansion of drought impacts under future climate scenarios underscore the need to strengthen the resilience of cattle production systems. Targeted investments will be crucial in reducing vulnerability, particularly in high-risk areas. Without timely and coordinated adaptation measures, climate change is likely to amplify existing pressures, placing increasing strain on livelihoods, food security, and the regional livestock economy.

PIGS

The maps of pig populations in Zambia's Eastern Province illustrate a spatial pattern of drought impacts under current and future climate conditions.

Under current conditions (2025), drought-related impacts on pigs are relatively limited and concentrated in specific districts, particularly in the southern and eastern parts of the province, such as Chipata, Katete, Chadiza, and Lundazi. Under the future RCP 8.5 scenario (2050), the maps indicate a substantial intensification and expansion of drought impacts across much of the province (Figure 17). High-impact hotspots are located across central and southern districts, with a marked increase in the expected number of pigs affected by drought. This shift highlights the growing vulnerability of pig production systems to climate change, driven by increased competition for water, reduced availability of feed resources, and higher heat stress, underscoring the need for targeted adaptation measures in mixed crop–livestock systems.

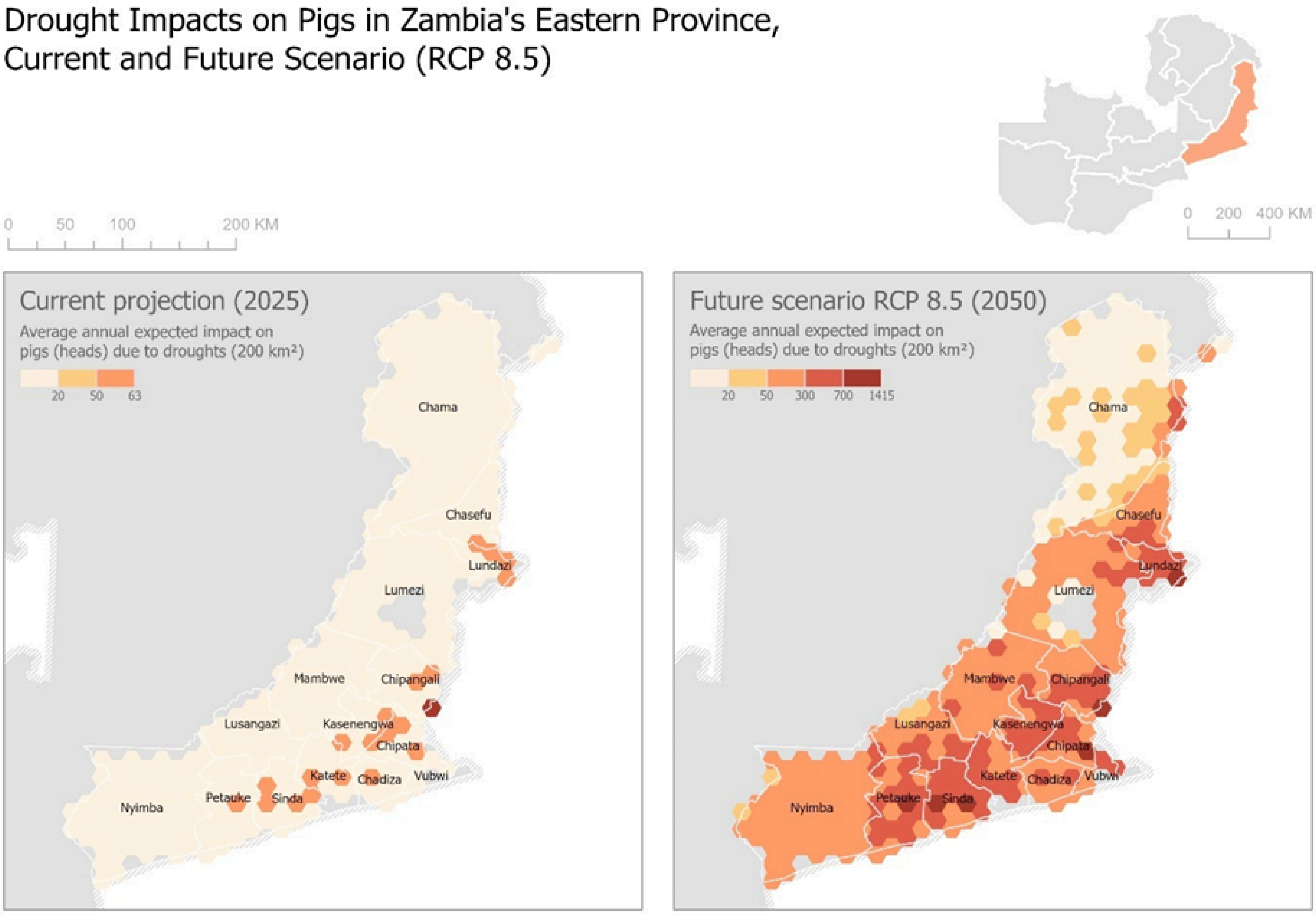


Figure 17: Drought impacts on pig population for current and future (2050, RCP 8.5) scenarios.

Pig production also faces increasing drought-induced economic losses. Presently, average annual losses are estimated at USD 92,000. Anticipated economic growth could increase these losses by an additional USD 188,000 per year by 2050. Climate change is estimated to contribute between USD 1 million and USD 1.8 million under RCP 4.5 and RCP 8.5, respectively. In total, projected annual losses for pigs due to drought impacts may reach USD 1.3 million under a moderate climate change scenario and USD 2 million under a severe climate change scenario (Figure 18).

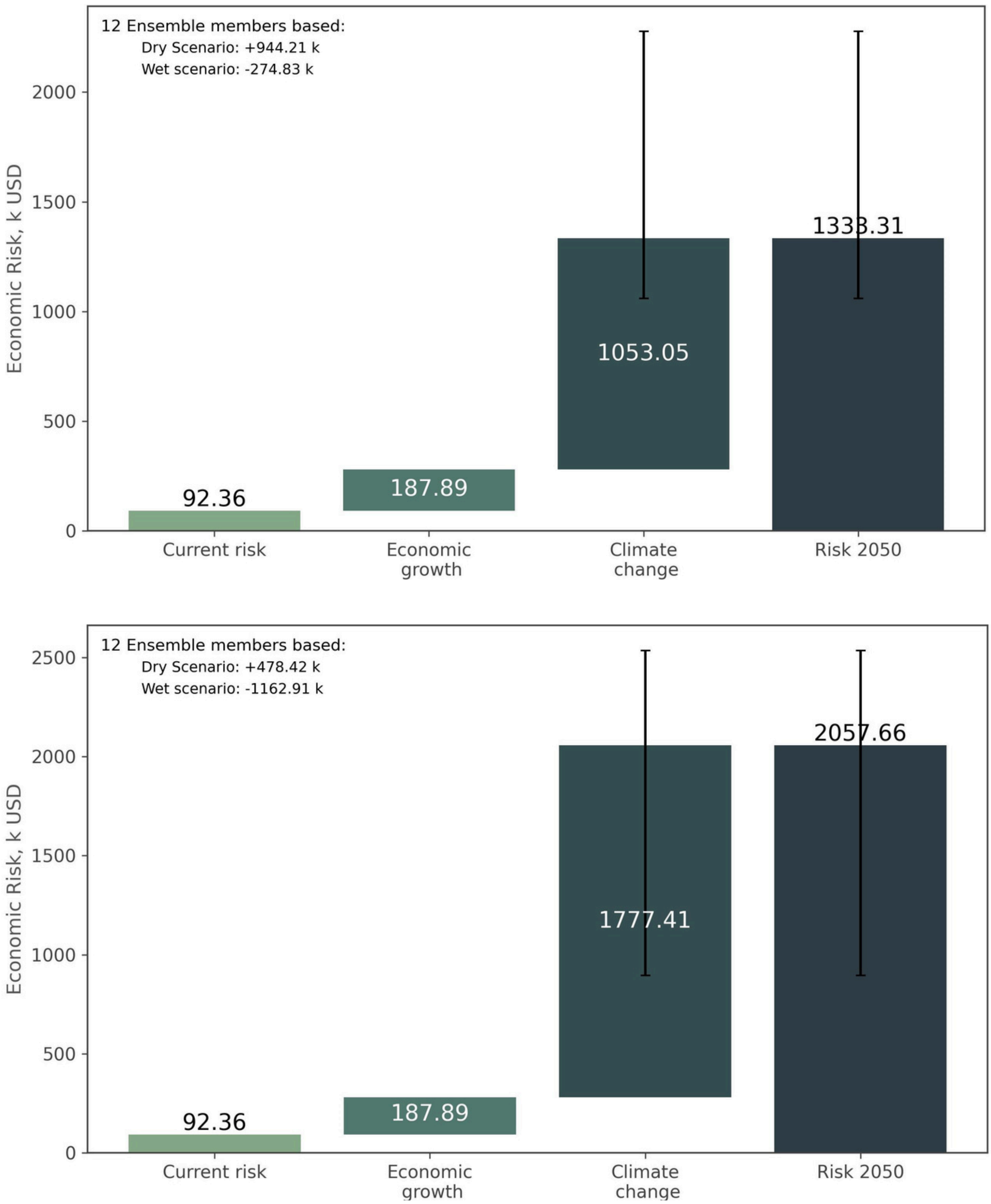


Figure 18: Average annual pig losses in USD due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

Overall, drought-related impacts on pig production are expected to intensify as climate change exacerbates water scarcity and heat stress, with effects on animal health and productivity. Although pig systems are less dependent on grazing, their reliance on water and feed inputs makes them vulnerable to prolonged drought conditions. Enhancing housing, water management, and feed security will therefore be critical to reducing future losses and improving the resilience of pig production systems.

2.2.3 DROUGHT IMPACTS ON PEOPLE

Drought is a key driver of food insecurity in Zambia, particularly in drought-prone regions such as the Eastern Province, where livelihoods are highly dependent on rainfed agriculture. The results of the CLIMADA-driven current and future risk analyses indicate that drought-related food insecurity (IPC Phase 3+) is already significant and projected to increase substantially by 2050 under a high-emissions climate scenario (RCP8.5).

The spatial analysis of drought-related food insecurity (IPC Phase 3+) in Figure 19 highlights both the current and projected severity of impacts. The maps show the average annual expected number of people exposed to drought-induced food insecurity at a 20 km² resolution, revealing pronounced hotspots along the southern and eastern districts of the province. Districts such as Chipata, Katete, Petauke, Chadiza, and Lundazi already exhibit elevated levels of food insecurity under current conditions. Under the future climate scenario (RCP 8.5, 2050), the maps indicate an expansion and intensification of food insecurity hotspots. Areas currently experiencing moderate risk are shifting towards substantially higher levels of affected populations, while new high-risk clusters are emerging across much of the province.

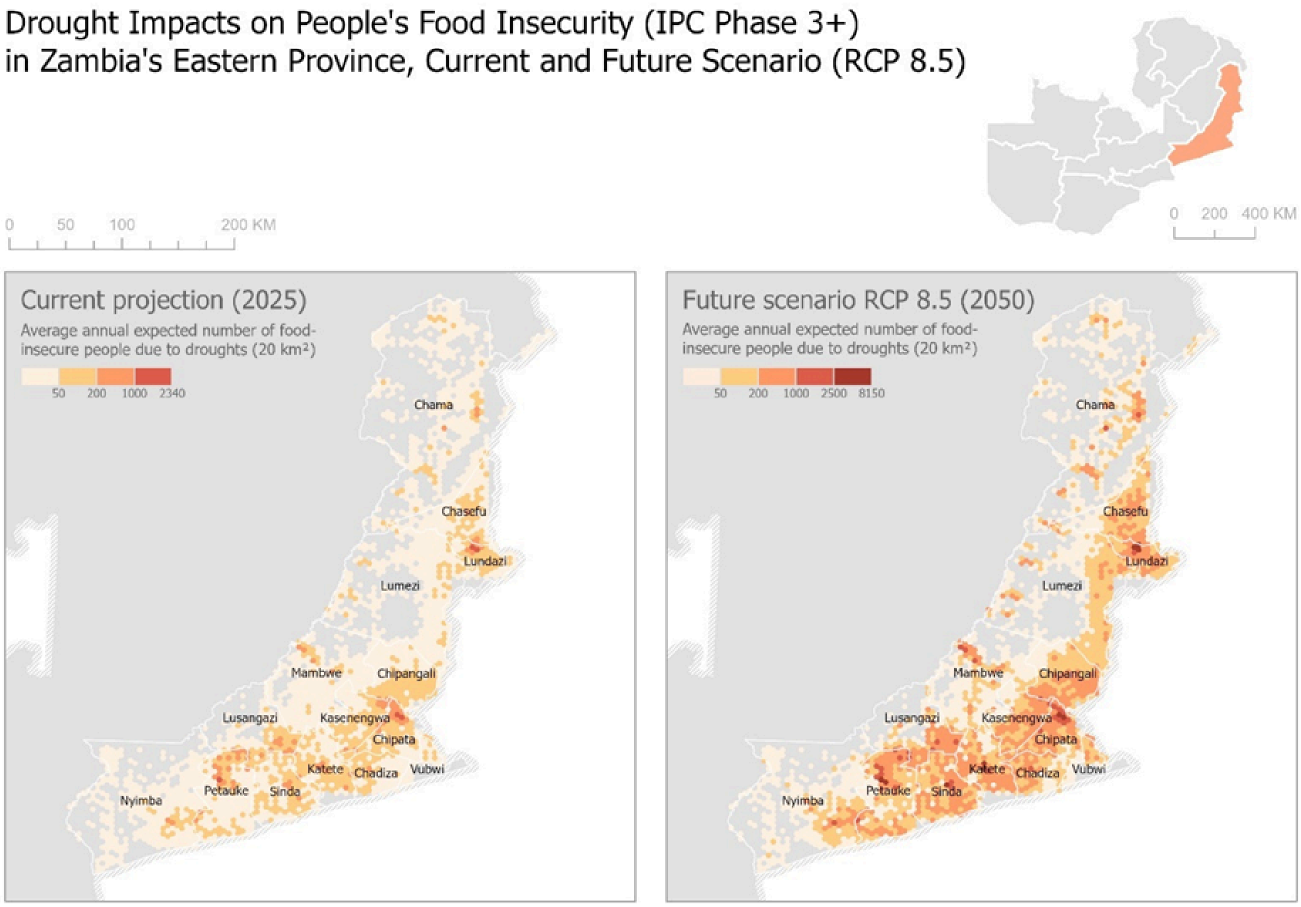


Figure 19: Drought impacts on people for current and future (2050, RCP 8.5) scenarios.

Population growth and climate change together amplify the number of people exposed to drought-induced food insecurity, with climate change emerging as the dominant driver of increased risk in future projections. As Figure 20 indicates, on average, 116,000 people are food insecure due to droughts every year under the current scenario. This value represents the average of all years, regardless of whether a no drought, a mild drought, or a severe drought was registered. Food insecurity can have many drivers, but these numbers only apply to drought-induced food insecurity. The whiskers indicate further uncertainties in climate change resulting from the incorporation of different drought scenarios in the calculation.

By 2050, due to population growth, an additional 100,000 people are projected to be food insecure on average each year. Including climate change in the model, the results show that for the moderate climate change scenario (RCP 4.5), an additional 130,000 people on average will be food insecure due to droughts every year. Together with the estimated population growth and the current risk, over 346,000 people are projected to be food insecure due to droughts annually under the moderate climate change scenario. For the severe climate change scenario (RCP 8.5), these numbers translate to approximately 413,000 people affected by drought each year. The increase in the total number is due to the increased impacts of climate change on people's livelihoods and food availability, accessibility, and affordability during drought.

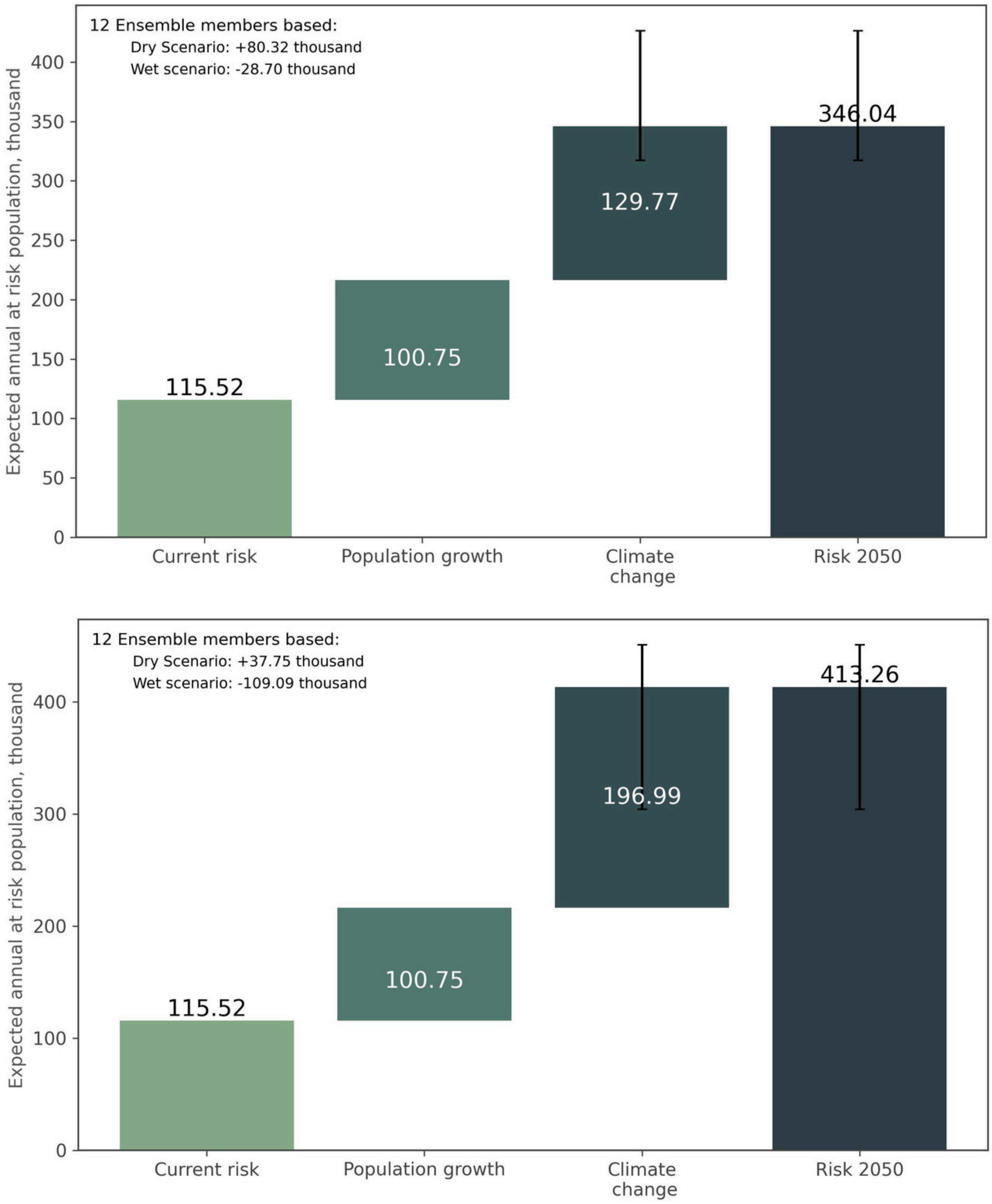


Figure 20: Average Annual number of People facing food insecurity due to droughts today and for different climate change scenarios (RCP 4.5 top and RCP 8.5 bottom) in the future (year 2050).

There is a lack of gender-disaggregated datasets on food and nutrition security in Zambia; therefore, this analysis does not include gender-specific numbers. However, it needs to be kept in mind that households experiencing food insecurity, women, and children face a significantly higher risk of malnutrition compared to men, reflecting unequal access to food, care burdens, and coping strategies during shocks. This vulnerability is exacerbated by limited dietary diversity, as on-farm food baskets are predominantly composed of maize, the primary staple crop. Heavy reliance on maize increases sensitivity to drought, reduces nutritional adequacy, and constrains household resilience in the face of climate variability.

3.

ADAPTATION ASSESSMENT

Please refer to Chapter **Adaptation Assessment, **Preparation for CLIMADA Adaptation Modelling**, and **CLIMADA Adaptation Modelling** in the technical Annex for further details.*

This chapter describes the possibilities for adaptation to reduce the losses and damages induced by drought and exacerbated by climate change. Three Adaptation Pathways have been developed, each characterized by a specific composition of adaptation measures and distinguished by their individual benefits and opportunities to provide positive adaptation benefits for the Agricultural Sector in the Eastern Province. This chapter explains the Adaptation Pathways and their corresponding adaptation measures, suggests an investment plan for implementation, and provides a comparison of the three Pathways and their adaptation potential.

The Adaptation Pathways are actionable and budget-sensitive recommendations for implementing targeted bundles of adaptation measures, conceptualized in accordance with the priorities of provincial stakeholders. The Pathways guide stakeholders, such as agricultural ministries in the Eastern and Southern Regions, in assessing feasible climate adaptation actions with different timelines, scopes, and across various funding levels. The three Pathways are called a) Effectiveness, b) Green Sustainable Future, and c) Food Security.

For each of the three Pathways, opportunities for adaptation under domestic and international investments have been calculated to consider varying budget scenarios. The Pathways showcase the possibilities for the Zambian government to reduce drought-related damages by investing USD 1 million every four years through its domestic budget until 2050. If international funding can be secured, adaptation actions can be implemented on a larger scale, securing more livestock and crops, and safeguarding people from food insecurity. To this end, Chapter 3.1 provides perspectives for potential international funding opportunities. We are calculating the scales of implementation and avoiding drought-related damages by investing international budgets in Pathways, with investments of USD 10 million every four years.

Following the requests of Zambian stakeholders, the Adaptation Roadmaps are action-oriented tools that directly support decision-making for adaptation. In that regard, the Roadmaps are practical, offering clear guidance on implementing sustainable crop and livestock strategies to strengthen local food security and overall resilience against drought. Therefore, the Roadmaps provide transparent prioritization and financing guidance, allowing policymakers to select measures based on their cost-effectiveness, alignment with provincial and national priorities, and access to suitable funding instruments.

This assessment evaluates three complementary adaptation pathways designed to address drought risks while balancing effectiveness, sustainability, and food security outcomes. The **Effectiveness pathway** prioritizes measures that can deliver rapid and high-impact results at relatively low cost, emphasizing ease of implementation and direct reductions in drought impacts on agriculture and livestock systems. The **Green Sustainable Future pathway** focuses on longer-term, environmentally sustainable solutions, promoting nature-based and climate-smart measures that are coherent with national policies, development plans, and green growth strategies. Finally, the **Improving Food Security pathway** centers on social co-benefits, targeting interventions that strengthen household and community food security during droughts through improved production, nutrition, and access to climate information. Together, these pathways provide a structured framework for comparing adaptation options across regions and for identifying portfolios of measures that respond to immediate needs while supporting long-term resilience. Table 1 gives an overview of the Pathways considered and the respective measures.

Table 1: Overview of Adaptation Pathways.

PATHWAY	EFFECTIVENESS	GREEN SUSTAINABLE FUTURE	IMPROVING FOOD SECURITY
Criteria	*Cost, Ease of Implementation, Effectiveness*	*Sustainability, Green Measures, Coherence with Policies and Plans*	*Food Security (Co-benefits, Social)*
Rationale	Focuses on delivering high-impact results at low cost through easily implementable solutions that directly reduce drought impacts.	Prioritizes long-term, nature-based solutions that align with national strategies.	Promotes measures that directly aim to reduce food security during droughts
Measures	*· Drought-tolerant crops* *· Locally adapted livestock* *· Climate Smart Agriculture*	*· Drought-tolerant crops* *· Climate Smart Agriculture* *· Agroforestry*	*· Post-harvest, and preservation techniques* *· Early warning, automatic weather stations, and dissemination of climate services* *· Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)*

3.1 THE EFFECTIVENESS PATHWAY

The **Effectiveness Pathway** focuses on delivering high-impact results at low cost through easily implementable solutions that directly reduce drought impacts. It is defined by three core criteria: cost-efficiency, ease of implementation, and direct effectiveness in reducing drought impacts. Measures in this Pathway excel as they deliver rapid, tangible benefits with relatively low investment requirements and minimal institutional complexity. They are designed to stabilize agricultural production quickly and to provide immediate support to households affected by drought.

The Adaptation Pathway follows two investment scenarios, as shown in Figure 21: the domestic and the international investment. The domestic investment scenario is based on the annual budget of Zambia's Ministry of Agriculture and calculates an investment of USD 1 million every four years until 2050. This amounts to a total budget of USD 6 million until 2050. The international investment scenario is based on stakeholder consultations of reasonable project budgets and calculates an investment of USD 10 million every four years until 2050. This amounts to a total budget of USD 60 million until 2050.

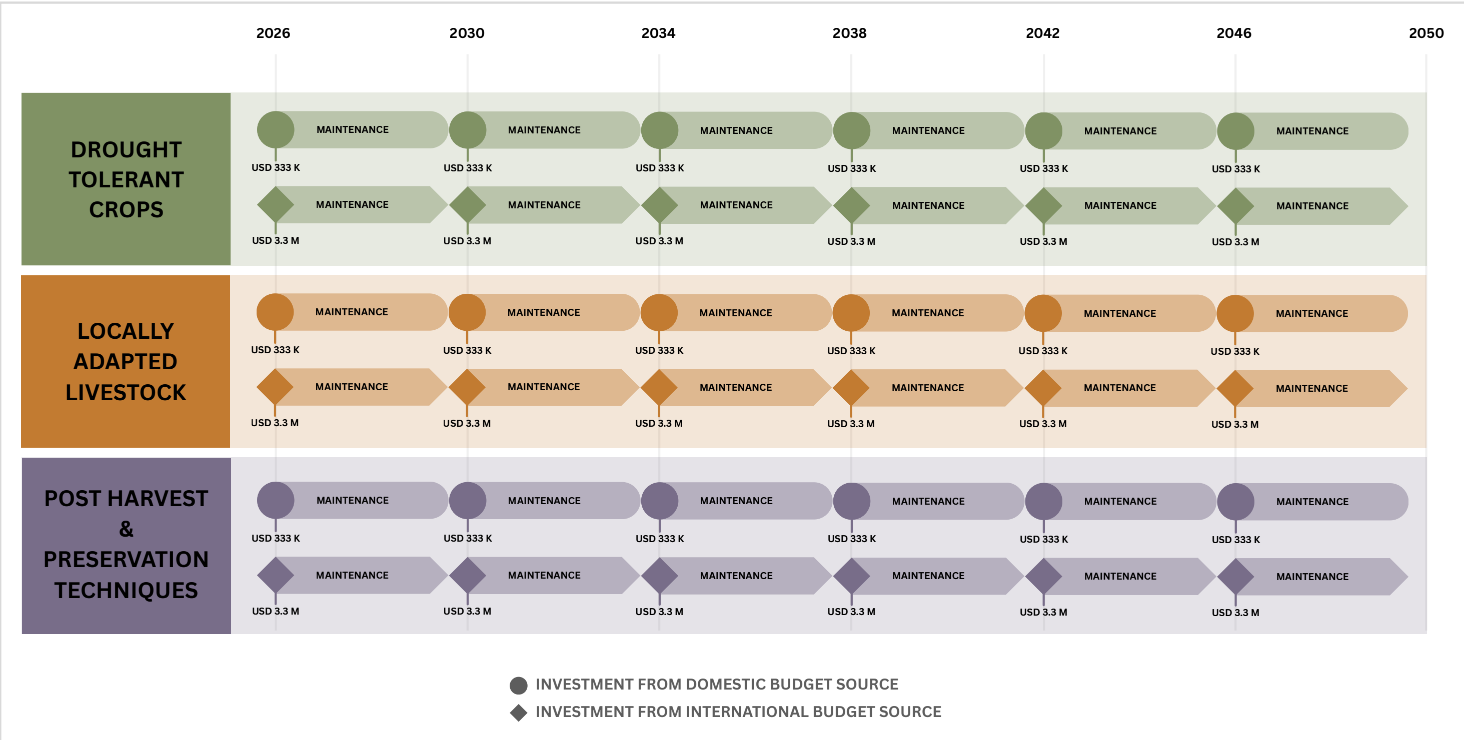


Figure 21: Investment scenarios for the Effectiveness Pathway.

The adaptation measures selected for this Pathway performed strongly across these criteria. Drought-tolerant crops were included because they offer immediate improvements in yields under water-stressed conditions, require minimal additional training, and can be rapidly scaled through existing input distribution systems. Locally adapted livestock scored highly because indigenous breeds are already familiar to farmers, demand fewer resources, and withstand high temperatures, making them an efficient and low-risk strategy during prolonged dry periods. Post-harvest and preservation technologies also ranked high due to their straightforward implementation, low cost, and strong ability to reduce food losses—directly improving food availability even when production declines. Together, these measures reflect an approach centered on fast, practical, and cost-effective drought resilience.

Drought-Tolerant Crops

Introducing drought-tolerant crop varieties is a key adaptation strategy for stabilizing and increasing agricultural production in Zambia under increasingly erratic rainfall conditions. These crops enable farming households to sustain yields even when water availability is limited, thereby supporting income generation as well as food and nutrition security during drought years. Implementation commonly follows a lead–follower farmer model, in which selected lead farmers receive start-up input packs and participate in training and demonstration activities, allowing practical knowledge on land preparation, planting, and crop management to spread efficiently within communities over the agricultural season (typically September to July). Drought-tolerant options already available in Zambia include improved maize varieties, alongside improved groundnut varieties such as MGV 8, MGV 7, and Wamusanga(Mpofu 2023). For soybeans, drought-tolerant varieties developed by the International Institute of Tropical Agriculture notably TGx1740-2F ("Kafue") and TGx1937-1F ("Mwembeshi")—offer early maturing, drought-tolerant, and disease-resistant options, supported through public-sector breeding efforts funded by partners such as the Bill and Melinda Gates Foundation (Chigeza et al. 2019). In addition, Zambia's National Institute for Scientific and Industrial Research (NISIR) is actively testing drought-tolerant sweet potato and cassava varieties that require minimal water, with the aim of recommending suitable varieties for drought-prone regions such as Southern Province (Ministry of Technology and Science Zambia n.d.). In summary, drought-tolerant varieties provide an accessible and effective strategy for safeguarding crop production and livelihoods during droughts.

Locally Adapted Livestock

Promoting locally adapted (indigenous) livestock breeds is a highly effective drought adaptation measure, as these animals are inherently better suited to local climatic and environmental conditions (Global Center on Adaptation 2023) . Indigenous breeds generally require less water, tolerate higher temperatures, and exhibit greater resistance to local diseases than improved breeds, enabling them to maintain productivity under drought and heat stress. This resilience supports sustained meat and milk availability, contributing to household nutrition and income at relatively low production costs. Africa's livestock sector is characterized by high genetic diversity, with over 150 recognized local cattle breeds, whose traits—such as heat tolerance, disease resistance, and drought coping capacity—are increasingly critical under climate change. Heat stress is known to reduce productivity, weaken immune systems, lower reproductive performance, and increase mortality, although impacts vary by breed and species. (Global Center on Adaptation 2023)

Implementation commonly follows a pass-on model, where selected farmers receive indigenous animals and later transfer offspring to other households, gradually expanding access and strengthening local herds. By reinforcing local gene pools and scaling drought-tolerant livestock populations—particularly in heat-prone valley areas—this pathway offers a robust and culturally accepted strategy for securing livelihoods under increasingly dry climatic conditions.

Post-Harvest and Preservation Techniques

Post-harvest management is a critical adaptation measure for improving food security and resilience to drought in Zambia. According to the African Postharvest Losses Information System (APHLIS), farmers in Zambia lose approximately 17% of maize after harvest each year, highlighting the scale of avoidable food losses (APHLIS n.d.). Post-harvest management encompasses the handling, processing, storage, and transport of agricultural products after harvest, with the aim of preserving quality, nutritional value, quantity, and food safety by preventing pest infestation and contamination (GIZ 2024). When effectively applied, these practices extend shelf life, reduce food loss along the supply chain, ensure year-round food availability, increase farmer incomes, and add value to agricultural products. In contrast, poor post-harvest management can significantly reduce usable yields, lower market value, and pose serious health risks through contamination, such as aflatoxins (GIZ 2024). Zambia's shift toward decentralized storage systems—through local storage clusters, small grain silos, farmer training, and improved access to inputs—has already demonstrated success in reducing post-harvest losses and maintaining crop availability for markets. Traditional preservation methods, such as drying groundnuts or mushrooms, also remain important, though continued research and innovation are needed to improve their safety and reduce toxin risks. Implementation typically follows a lead–follower farmer model, combining training, equipment provision, and improved storage facilities. By strengthening post-harvest practices alongside production, this pathway helps communities retain more of what they grow, reduces food insecurity during drought years, lowers greenhouse gas emissions from food loss, and enhances household resilience across all districts. (The Zero Hunger Coalition 2024)

Impact on Reducing Drought Risk and Vulnerability

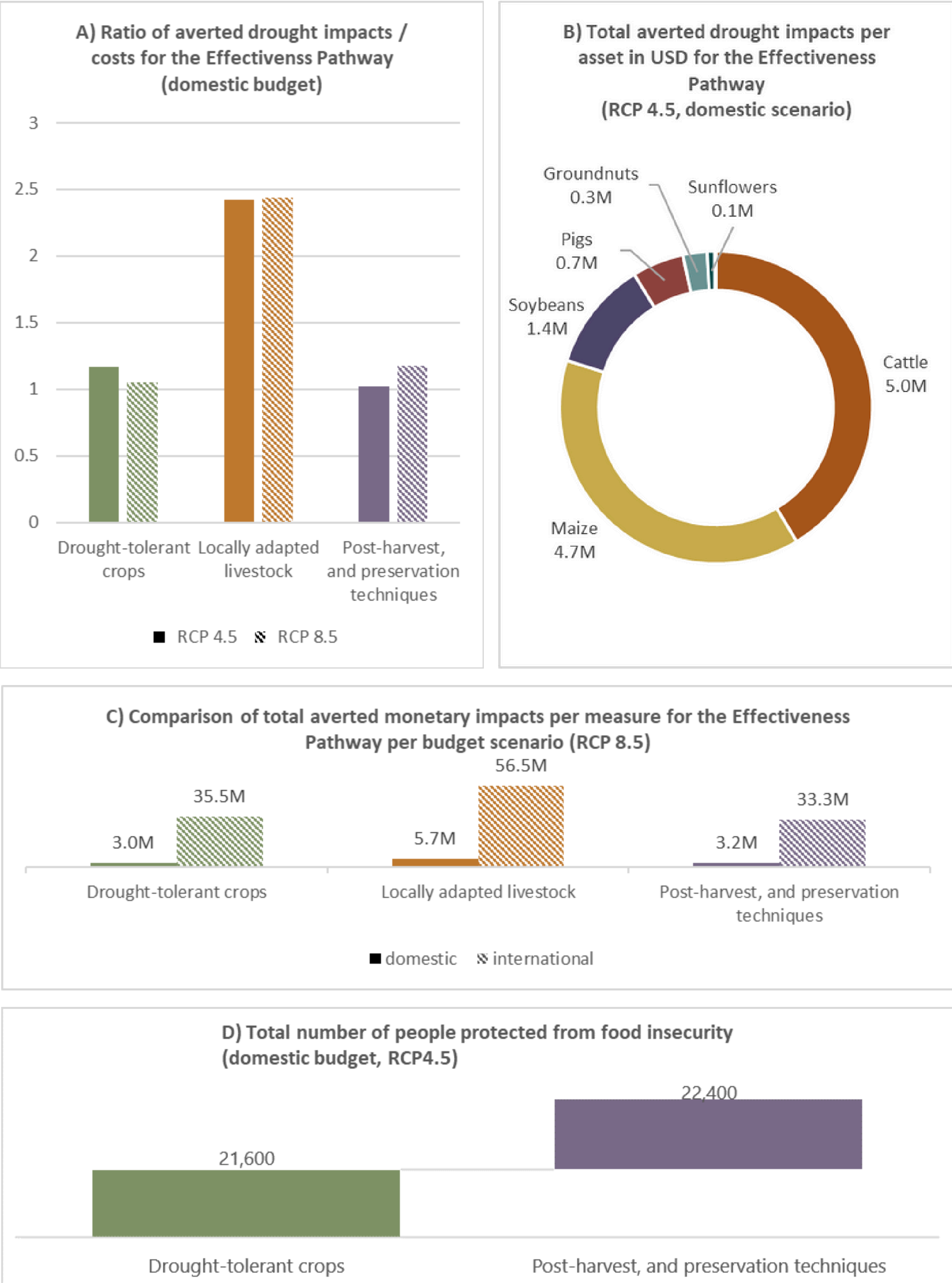


Figure 22: Key modelling outcomes of the Effectiveness Pathway.

The results of modelling the impact of the Effectiveness Pathway show how different adaptation measures perform in reducing drought-related damages to crops and livestock, focusing on their economic efficiency and immediate impact. The charts (Figure 22) presented in this section compare the benefit–cost (B/C) ratios and the absolute value of averted damages under moderate and severe climate change scenarios, considering different budget scenarios. This analysis translates modelling results into clear insights for decision-makers and adaptation planners.

Across all measures and climate scenarios, B/C ratios are consistently above 1, indicating that investments in these measures are economically justified even when considering only the benefits from avoided drought damages, as shown in Figure 22 A. In other words, for every USD invested, more than one USD in drought-related losses is prevented. Importantly, these calculations are conservative, as they do not yet include additional co-benefits such as higher average yields, improved resistance to pests and diseases, or broader benefits to livelihoods and ecosystems. Accounting for these factors would further increase the overall return on investment.

Among all measures assessed, locally adapted livestock shows the highest B/C ratio, reflecting the strong resilience of indigenous breeds to drought, heat stress, and local diseases. While direct comparisons between crops and livestock should be interpreted with caution, given their different production systems and asset values, the results clearly highlight livestock adaptation through locally adapted livestock as a highly cost-effective strategy. The cost-effectiveness of drought-tolerant crop varieties remains high overall, though their B/C ratio decreases slightly under the more severe climate change scenario (RCP 8.5), as extreme conditions begin to outweigh some of the gains from varietal improvements. In contrast, post-harvest management measures show a higher B/C ratio under RCP 8.5, reflecting their increasing importance as droughts intensify and harvest losses become more costly.

In absolute terms, the largest annual averted damages are observed for cattle, with approximately USD 5 million in drought-related losses avoided for the domestic budget scenario, as Figure 22 B shows. This reflects both the high vulnerability of cattle to drought and their high economic value, which can both be protected if transitioning to adapted and more drought-resilient species. Even for smaller livestock, such as pigs, the use of locally adapted breeds yields substantial benefits, with approximately USD 700,000 in avoided losses, underscoring the importance of this measure across livestock systems.

For crops, the charts indicate that the largest monetary benefits are derived from protecting maize, Zambia's dominant staple crop. By implementing the suggested adaptation measures in the Effectiveness Pathway targeting maize with the domestic budget, i.e., drought-tolerant varieties and post-harvest and preservation methods, roughly USD 4.7 million can be saved in averted drought damages. However, with these adaptation measures, significant benefits are also observed for soybeans, with around USD 1.4 million in avoided losses due to drought under domestic investment.

When total averted damages are aggregated at the pathway level under the high-emissions scenario (RCP 8.5) (Figure 22 C), locally adapted livestock again emerges as the most effective option in monetary terms. Under a domestic investment scenario—equivalent to USD 1 million invested every four years—the pathway yields approximately USD 5.7 million in total averted damages, of which about USD 5 million comes from cattle and USD 0.7 million from avoided damages for pigs. These results demonstrate that even relatively modest, nationally financed investments can deliver substantial economic returns.

The analysis also reveals clear scaling effects, particularly for drought-tolerant crops. Under an international investment scenario of USD 10 million every four years, the total value of averted drought damages across all crops increases substantially—from around USD 3.0 million under the domestic budget to approximately USD 35 million under the international budget scenario. This suggests that, with sufficient financing, crop-based adaptation measures can be rapidly expanded and generate disproportionately higher benefits.

For people, both adaptation measures that target individuals and their food security, namely drought-tolerant crops, and post-harvest and preservation techniques, protect a similar number of people, roughly 22,000, from drought-induced food insecurity under the domestic investment scenario and the moderate climate change scenario. The measures also support food security overall, so the general benefits of implementing them will yield higher outcomes for people's livelihoods, as this is a conservative calculation focused solely on the drought context. For one thousand USD invested under the RCP 4.5 scenario, 34 people can be protected from food insecurity by these measures during droughts.

Overall, the Effectiveness Pathway demonstrates that targeted adaptation investments can substantially reduce drought-related damages across both crop and livestock systems by introducing drought-tolerant crops, locally adapted livestock, and post-harvest and preservation techniques. The results underscore three key messages: first, adaptation pays off even under severe climate change scenarios; second, locally adapted livestock offers particularly high and immediate returns; and third, scaling up investments—especially in drought-tolerant crops—can unlock significantly larger benefits. Together, these findings provide strong evidence for prioritizing cost-effective and scalable measures as part of this Effectiveness Pathway to enhance drought resilience in Zambia's Eastern Province.

3.2 THE GREEN SUSTAINABLE FUTURE PATHWAY

The **Green Sustainable Future Pathway** prioritizes long-term, nature-based solutions that align with national strategies. It is defined by criteria related to sustainability, green and nature-based practices, and coherence with national and subnational policies and plans. Measures in this Pathway promote long-lasting ecological benefits, strengthen ecosystem services, and align closely with Zambia's broader climate and agricultural strategies. They emphasize resilience-building through improved soil health, biodiversity, and sustainable land management.

The Adaptation Pathway follows two investment scenarios, as shown in Figure 23: the domestic and the international investment. The domestic investment scenario is based on the annual budget of Zambia's Ministry of Agriculture and calculates an investment of USD 1 million every four years until 2050. This amounts to a total budget of USD 6 million until 2050. The international investment scenario is based on stakeholder consultations of reasonable project budgets and calculates an investment of USD 10 million every four years until 2050. This amounts to a total budget of USD 60 million until 2050.

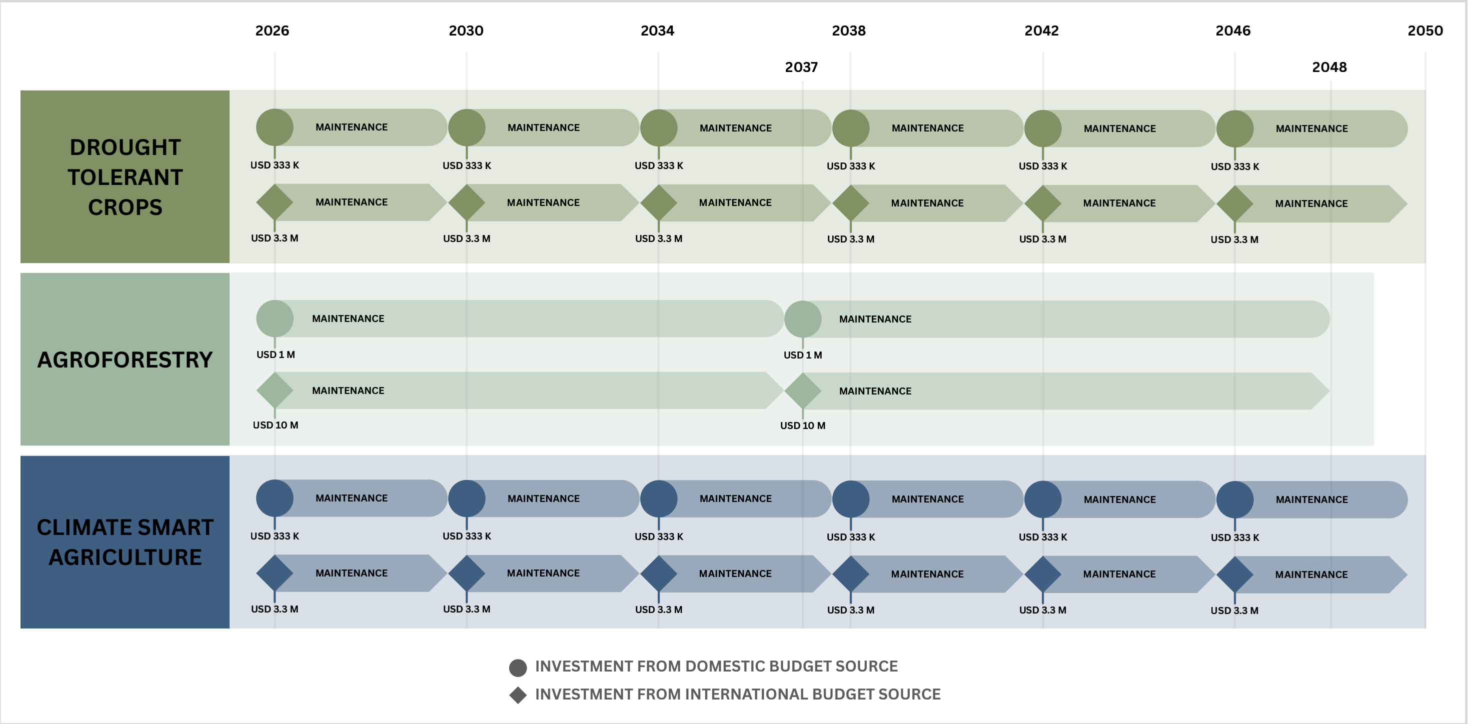


Figure 23: Investment Scenarios for the Green Sustainable Future Pathway.

The measures identified for this Pathway reflect strong performance on these criteria. Drought-tolerant crops were included because they serve as an important foundation for sustainable agricultural systems, aligning with national crop diversification and resilience objectives. Agroforestry ranked particularly high due to its strong nature-based profile, long-term soil enhancement, carbon sequestration potential, and alignment with green development priorities. Climate-smart agriculture practices—including crop rotation, minimum tillage, residue retention, and organic soil amendments—were selected because they substantially improve soil moisture retention, fertility, and sustainable land use, while matching policy targets for climate-resilient agriculture. Collectively, these measures create a long-term, ecologically grounded Adaptation Pathway.

Drought-Tolerant Crops

Introducing drought-tolerant crop varieties is a key adaptation strategy for stabilizing and increasing agricultural production in Zambia under increasingly erratic rainfall conditions. These crops enable farming households to sustain yields even when water availability is limited, thereby supporting income generation as well as food and nutrition security during drought years. Implementation commonly follows a lead–follower farmer model, in which selected lead farmers receive start-up input packs and participate in training and demonstration activities, allowing practical knowledge on land preparation, planting, and crop management to spread efficiently within communities over the agricultural season (typically September to July). Drought-tolerant options already available in Zambia include improved maize varieties, alongside improved groundnut varieties such as MGV 8, MGV 7, and Wamusang (Mpofu 2023). For soybeans, drought-tolerant varieties developed by the International Institute of Tropical Agriculture notably TGx1740-2F ("Kafue") and TGx1937-1F ("Mwembeshi")—offer early maturing, drought-tolerant, and disease-resistant options, supported through public-sector breeding efforts funded by partners such as the Bill and Melinda Gates Foundation (Chigeza et al. 2019). In addition, Zambia's National Institute for Scientific and Industrial Research (NISIR) is actively testing drought-tolerant sweet potato and cassava varieties that require minimal water, with the aim of recommending suitable varieties for drought-prone regions such as Southern Province (Ministry of Technology and Science Zambia n.d.). In summary, drought-tolerant varieties provide an accessible and effective strategy for safeguarding crop production and livelihoods during droughts.

Agroforestry

Agroforestry represents a highly effective drought adaptation measure in Zambia, with strong potential to enhance long-term resilience of smallholder farming systems. By integrating trees into croplands, agroforestry improves soil structure and fertility, increases water infiltration and retention, and creates beneficial microclimates that reduce crop stress during prolonged dry periods. Evidence from Nyimba District, in the Eastern Province of Zambia demonstrates that smallholder households adopting agroforestry practices are significantly more resilient to climate shocks than non-adopters, with higher and more stable agricultural productivity (Chavula et al. 2023). These gains translate into improved household incomes as well as strengthened food and nutritional security under drought conditions. Implementation typically involves the establishment of seed and seedling banks, demonstration plots, and farmer field schools, alongside training of lead and follower farmers in tree–crop integration. While an initial establishment period of around one year is required, the long lifespan of agroforestry systems—often extending over a decade—ensures sustained benefits.

Climate-Smart Agriculture

Climate-Smart Agriculture (CSA) is an approach that guides the transformation of agri-food systems toward practices that are both environmentally sustainable and resilient to climate change. In Zambia, CSA has demonstrated clear long-term benefits for soil health and maize productivity across diverse agroecological zones, confirming its potential as a drought adaptation strategy.

However, adoption remains limited, as CSA requires time, collective community-level engagement, and supportive enabling conditions. Low uptake is largely driven by structural constraints, including heavy reliance on maize-based systems, unequal access to subsidies, and inadequate agricultural infrastructure, underscoring the need for targeted investments in irrigation, modern CSA technologies, and institutional support. Empirical evidence further shows that sustained CSA practices—particularly those combining minimum soil disturbance with legume rotations—can partially substitute chemical fertilizers, improving soil fertility, lowering input costs, and delivering long-term economic and environmental benefits. (Nyirenda 2024)

Overall, CSA strengthens drought resilience by enhancing soil moisture retention, nutrient cycling, and productivity under water stress, thereby supporting stable yields, incomes, and food and nutrition security. Implementation typically follows a lead–follower farmer model, where selected farmers receive input packs and participate in training and demonstration activities focused on conservation practices such as crop rotation, reduced tillage, residue retention, and organic fertilization, making CSA a scalable and district-wide pathway for building resilient agricultural systems.

Impact on Reducing Drought Risk and Vulnerability

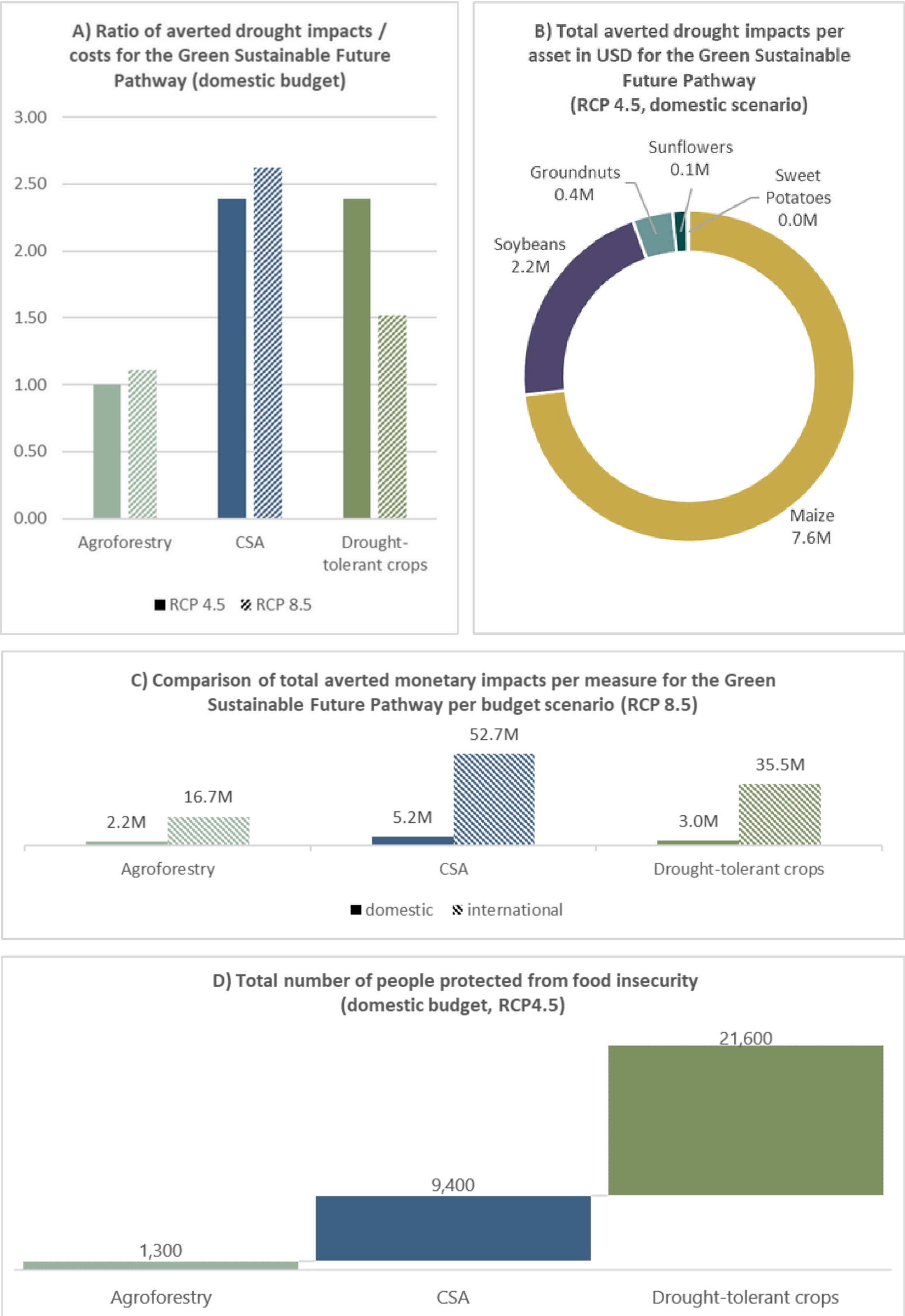


Figure 24: Key modelling outcomes of the Green Sustainable Future Pathway.

The Green Sustainable Future Pathway focuses on long-term, nature-based measures that reduce drought risk by improving soil health, enhancing water retention, and promoting ecosystem services, rather than merely stabilizing yields in the short term. The graphs in Figure 24 illustrate how drought-tolerant crops, agroforestry, and climate-smart agriculture jointly mitigate increasing levels of drought-related damages over time, with results shown for both domestic and international investment scenarios, as well as for moderate and severe climate change scenarios.

For the Green Sustainable Future Pathway, the benefit–cost ratios in Figure 24 A show that all three measures—agroforestry, climate-smart agriculture (CSA), and drought-tolerant crops—are economically viable for adaptation purposes, with CSA clearly standing out. Under the domestic budget, CSA achieves B/C ratios of about 2.3 under RCP 4.5 and 2.6 under RCP 8.5, meaning every USD invested prevents more than two USD in drought-related losses; this high efficiency reflects how CSA combines several practices at once (e.g. improved soil management, water management, conservation agriculture), so it can reduce yield losses in many years and across several crops simultaneously. Agroforestry shows a B/C ratio just above 1, which is lower in the short term because trees and associated soil improvements take time to mature. However, the overall B/C ratio still indicates that the value of avoided drought damages outweighs the costs during the 11-year implementation and maintenance period per adoption cycle. Drought-tolerant crops also achieve B/C ratios around 1.5, indicating that varietal improvements alone can significantly protect production against rainfall shocks, although their benefits can be partly offset under the most extreme droughts, when even tolerant varieties experience stress. For Agroforestry and CSA, even higher benefits are expected under the severe climate change scenario (RCP 8.5), indicating their high potential to enhance crop resilience even under conditions with more intense and frequent droughts.

The asset-level results, as shown in Figure 24 B, indicate that maize dominates the pie chart for total averted damages. With approximately USD 7.6 million in avoided drought damages under RCP 4.5 and the domestic budget, maize accounts for the largest share because it is the main staple, is planted on large areas, and is highly sensitive to rainfall variability; reducing its losses thus generates substantial monetary gains. Soybeans follow with roughly USD 2.2 million in averted losses, reflecting both their growing importance in the farming system and their vulnerability to prolonged dry spells, while sunflower (USD 0.4 million) and sweet potatoes (USD 0.1 million) contribute smaller values because they occupy less area and are comparatively more drought-tolerant already and thus the adaption measures CSA, Agroforestry, and drought-tolerant crop varieties have a lower total benefit, however, still support drought adaptation and save money.

The comparison of total averted damages per measure under RCP 8.5 highlights scaling effects when moving from domestic to international investment for CSA and drought-tolerant crops. Under the domestic budget, agroforestry, CSA, and drought-tolerant crops avert around USD 2.2 million, USD 5.2 million, and USD 3.0 million, respectively. These numbers already show that even modest investments of USD 1 million for all three measures together every four years can significantly reduce drought damages. Under the international budget, the same measures avert roughly USD 16.7 million, USD 52.7 million, and USD 35.5 million, respectively, indicating that larger, externally financed programmes allow these practices to be rolled out over much larger areas and across more households, thereby increasing avoided losses. CSA and drought-tolerant crops benefit particularly from this scaling because they are comparatively easy to disseminate (through inputs, training, and extension) and can be integrated into existing cropping systems without major structural changes (Figure 24 C). In contrast, agroforestry, although highly beneficial, expands more gradually due to longer establishment periods.

The analysis of benefits for people indicates that a total of 32,000 individuals are protected from food insecurity during droughts due to these adaptation measures in the domestic investment scenario under RCP 4.5 (Figure 24 D). The highest share of people protected falls under the measure “drought-tolerant crops” with 21,600 people protected annually under these conditions. The benefit-cost analysis shows that for each thousand USD invested into these measures, 25 people can be protected from food insecurity every year, in addition to the outlined monetary benefits.

Overall, the Green Sustainable Future Pathway demonstrates that, in the long term, nature-based adaptation measures can significantly reduce drought-related damages while delivering sustained economic and environmental benefits. The results highlight three key messages: first, climate-smart agriculture provides consistently high returns by improving soil and crop resilience across diverse conditions; second, this Pathway only focuses on crops, and strengthens in particular maize and soybean resilience; and third, scaling up investments—particularly through international financing—substantially amplifies avoided losses by enabling wider adoption across crops and regions for CSA and drought-tolerant crops. Together, these findings underscore the importance of prioritizing green, sustainable measures that not only mitigate drought risk today but also foster resilient agricultural systems for the future.

3.3 THE IMPROVING FOOD SECURITY PATHWAY

The **Improving Food Security Pathway** promotes measures that directly aim to reduce food security during droughts. It is defined by criteria emphasizing social benefits, no-harm considerations, and co-benefits, particularly those related to nutrition, household stability, and equitable access to resources. Measures in this Pathway directly target reductions in food insecurity during drought periods, ensuring that vulnerable households have reliable access to safe and nutritious food. They also promote early action to prevent crises, supporting no-regret decision-making under uncertainty.

The selected measures reflect strong scores in these domains. Fortified food crops were included because they enhance dietary diversity and micronutrient intake while offering shorter growing periods and reliable yields even under drought stress. Post-harvest and preservation techniques were selected for their significant social and food security benefits, enabling households to maintain consistent access to stored food while reducing losses and the need to expand production areas. Early warning systems, automatic weather stations, and climate information dissemination ranked highly for their strong no-harm and co-benefit profiles, as they enable timely planting decisions, improve community preparedness, and support equitable access to climate information. Together, these measures form a Pathway centered on safeguarding nutrition, reducing vulnerability, and ensuring food access during drought conditions.

The Adaptation Pathway follows two investment scenarios, as shown in Figure 25: the domestic and the international investment. The domestic investment scenario is based on the annual budget of Zambia's Ministry of Agriculture and calculates an investment of USD 1 million every four years until 2050. This amounts to a total budget of USD 6 million until 2050. The international investment scenario is based on stakeholder consultations of reasonable project budgets and calculates an investment of USD 10 million every four years until 2050.

This amounts to a total budget of USD 60 million until 2050.

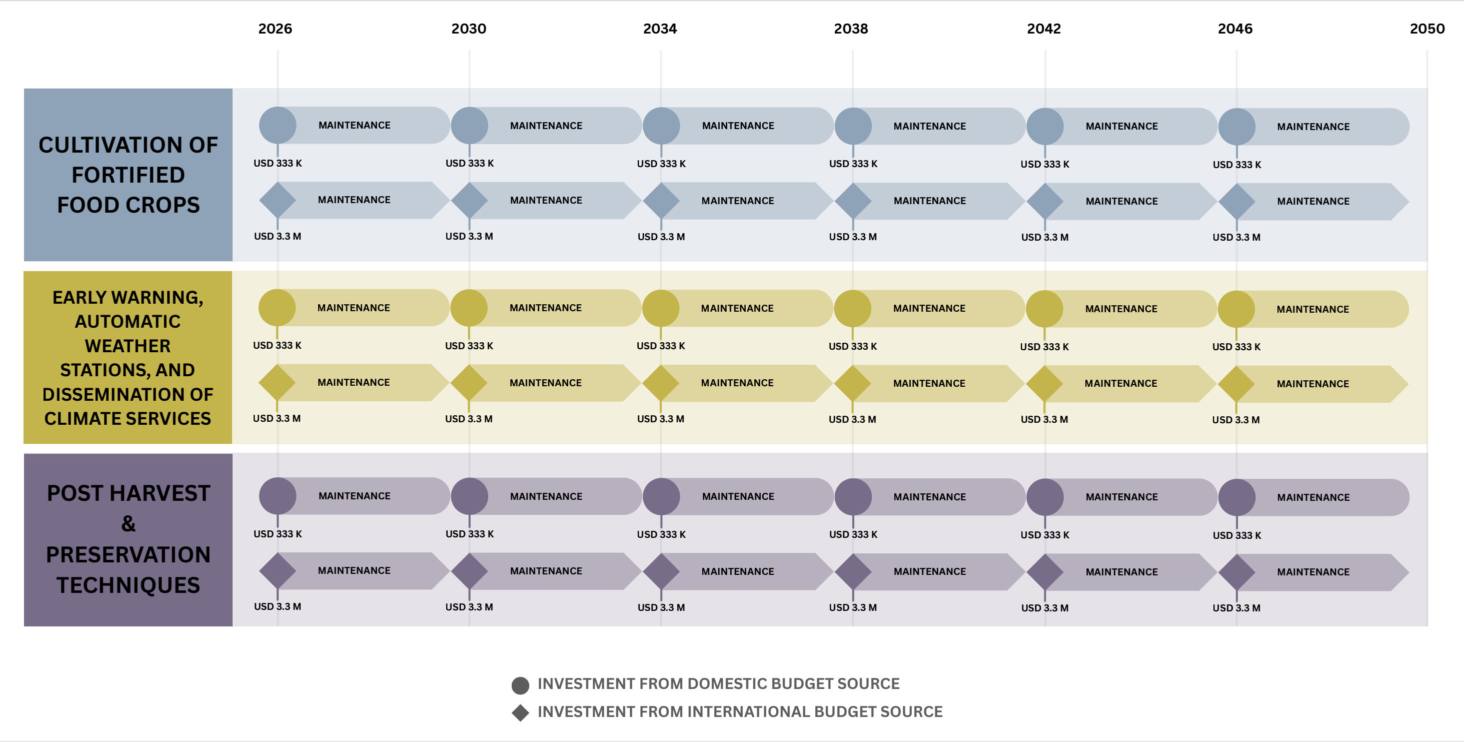


Figure 25: The investment scenarios for the Improving Food Security Pathway

The following sections present a set of complementary adaptation measures under the Improving Food Security Pathway, highlighting how targeted interventions in production, information, and food system management can reduce drought-related food insecurity. Together, these measures illustrate how combining nutritional strategies, timely climate information, and improved post-harvest practices can strengthen household resilience, protect livelihoods, and ensure more stable food availability under increasing climate stress.

Cultivation of Fortified Food Crops (Vitamin A–Maize, Orange-Fleshed Sweet Potatoes)

Fortified crops contribute both to drought resilience and nutritional security, offering shorter growing periods and improved tolerance compared to conventional varieties. Their enhanced vitamin A and micronutrient content directly addresses nutrition deficiencies while supporting household income and year-round food availability. Implementation uses the lead–follower farmer model, where selected farmers receive input packs and training on cultivation, harvesting, and marketing. By embedding fortified crops into crop diversification efforts, districts can achieve greater resilience: even when drought reduces yields, nutrient-dense crops provide more reliable nourishment and contribute to more stable food systems.

Early Warning Systems, Automatic Weather Stations, and Climate Information Services

Early warning systems, automatic weather stations, and climate information services play a critical role in strengthening drought resilience by enabling farmers and livestock keepers to make timely and informed decisions. Access to reliable climate information—such as seasonal forecasts and early warnings—helps producers determine optimal planting dates, select appropriate crop varieties, and manage water and other inputs more effectively under drought risk. Advances in climate prediction and interpretation, combined with the rapid expansion of mobile phone networks, have significantly improved the reach and usefulness of climate information for smallholders who previously had limited access. Digital technologies facilitate the dissemination of localized forecasts through radio, mobile platforms, and community channels, overcoming information barriers, strengthening extension services, and improving supply chain management. (Global Center on Adaptation 2023)

Implementation typically involves installing automatic weather stations across districts and ensuring that climate advisories are communicated in both English and local languages to maximize uptake. Evidence shows that timely climate information can reduce uncertainty, lower financial and labor costs, decrease production losses, and improve productivity. Ongoing initiatives supported by the World Bank and OneCGIAR are therefore exploring integrated approaches that combine climate information services with agricultural inputs and financial solutions, reinforcing proactive planning and significantly enhancing resilience to drought across agricultural systems. (Global Center on Adaptation 2023)

Post-Harvest and Preservation Techniques

Post-harvest management is a critical adaptation measure for improving food security and resilience to drought in Zambia. According to the African Postharvest Losses Information System (APHLIS), farmers in Zambia lose approximately 17% of maize after harvest each year, highlighting the scale of avoidable food losses (APHLIS n.d.). Post-harvest management encompasses the handling, processing, storage, and transport of agricultural products after harvest, with the aim of preserving quality, nutritional value, quantity, and food safety by preventing pest infestation and contamination (GIZ 2024). When effectively applied, these practices extend shelf life, reduce food loss along the supply chain, ensure year-round food availability, increase farmer incomes, and add value to agricultural products. In contrast, poor post-harvest management can significantly reduce usable yields, lower market value, and pose serious health risks through contamination, such as aflatoxins (GIZ 2024). Zambia's shift toward decentralized storage systems—through local storage clusters, small grain silos, farmer training, and improved access to inputs—has already demonstrated success in reducing post-harvest losses and maintaining crop availability for markets. Traditional preservation methods, such as drying groundnuts or mushrooms, remain important, although continued research and innovation are necessary to enhance their safety and mitigate toxin risks. Implementation typically follows a lead–follower farmer model, combining training, equipment provision, and improved storage facilities. By strengthening post-harvest practices alongside production, this pathway enables communities to retain more of what they grow, reduces food insecurity during drought years, lowers greenhouse gas emissions associated with food loss, and enhances household resilience across all districts. (The Zero Hunger Coalition 2024)

Impact on Reducing Drought Risk and Vulnerability

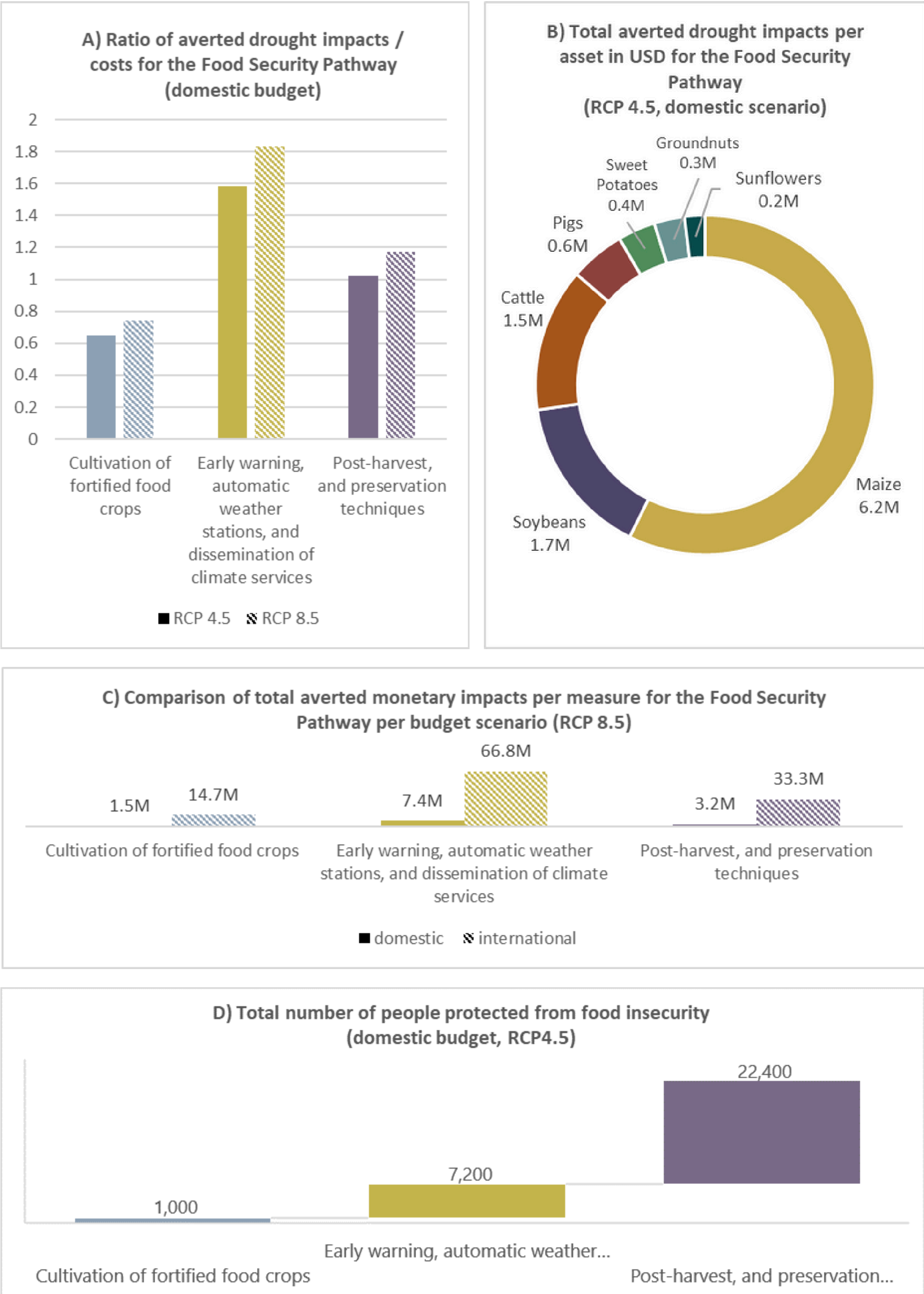


Figure 26: Key modelling results of the Improving Food Security Pathway

The Improving Food Security Pathway targets measures that directly reduce drought-induced food insecurity, emphasizing social co-benefits, “no harm” principles, and nutrition outcomes. The graphs in Figure 26 illustrate how the combination of fortified food crops, post-harvest and preservation techniques, and early warning and climate information services collectively reduces the number of people facing drought-related food insecurity and associated damages, across both domestic and international investment scenarios and various climate change scenarios.

For the Food Security Pathway, the B/C ratios in Figure 26 A show that measures that directly improve decision-making through the dissemination of climate information and reducing post-harvest losses are especially powerful in a drought context, being cost-effective in terms of reducing drought damages for each dollar invested. Under the domestic budget, cultivation of fortified food crops has B/C ratios around 0.7–0.8, which are slightly below those of the other measures because fortification and seed systems require upfront investment and their benefits are partly realized through improved nutrition rather than purely through avoided physical losses—benefits that are not fully captured in the drought-damage metric, but explained further for People below. Early warning, automatic weather stations, and climate services have the highest B/C ratios, increasing from around 1.5 under RCP 4.5 to about 1.8 under RCP 8.5; this reflects how timely climate information helps many farmers at once to adjust planting dates, crop choices, and herd management, thereby avoiding losses across a wide range of assets at relatively low operational cost even more under severe climate change conditions. Post-harvest and preservation techniques have B/C ratios around 1.0–1.1, indicating that interventions such as improved storage, drying, and processing quickly pay for themselves as they prevent harvested crops from being lost or spoiled. Here, it is also important to note that the avoided damages are only calculated for droughts. Since improved post-harvest and preservation techniques also show positive benefits under normal scenarios, the actual B/C ratio would be considerably higher.

The structure of averted damages by asset in Figure 26 B shows that maize dominates, with around USD 6.2 million in annual avoided drought damages under RCP 4.5 and the domestic budget. As the primary staple and a key contributor to both income and food intake, any improvement in protecting maize harvests from drought or post-harvest loss yields substantial financial benefits; this is compounded by its central role in local food security. Soybeans (about USD 1.7 million in avoided losses) also benefit substantially because they are both a cash crop and a protein source, so preservation and better management during droughts have significant economic value. Livestock (about USD 1.5 million for cattle and USD 0.6 million for pigs) gains mainly from improved early warning and climate services, which allow herders to act earlier—by moving animals, adjusting stocking rates, or planning feed and water—thus reducing mortality and distress sales. Smaller, but still important, benefits for sweet potatoes, groundnuts, and sunflower reflect their role as complementary food and income sources that can bridge gaps when maize fails, so protecting their production and storage contributes to overall resilience even if their individual monetary values are lower.

The RCP 8.5 comparison of total averted damages per measure under different budget scenarios illustrates how information and food system measures scale in practice. Under the domestic budget, fortified food crops, early warning and climate services, and post-harvest techniques avert around USD 1.5 million, USD 7.4 million, and USD 3.2 million, respectively, already indicating that even small national investments deliver clear gains. Under the international budget, these values increase to roughly USD 14.7 million, USD 66.8 million, and USD 33.3 million (Figure 26 C). The relatively lower increase for early warning and climate services (USD 7.4 million to USD 66.8 million for a budget increased tenfold from domestic to international) shows that already with a domestic investment, a good network of stations, communication channels, and advisory systems can be put in place, to protect very large numbers of people and assets. Contrarily, scaling post-harvest and preservation technologies under higher investment allows more households to store surplus food safely and for longer, which becomes critical as droughts intensify. This explains why the absolute amount of avoided damages increases with larger budgets.

The analysis of impacts on People and their food security, as shown in Figure 26 D, indicates that more than 30,000 people can be protected from food insecurity due to droughts by implementing these adaptation measures. The most effective measure in terms of ensuring food security is the Post-harvest and preservation techniques, which protect 22,000 people. Fortified food crops show the lowest impact of protecting people from food insecurity during droughts, with only 1,000 people protected. This may be due to the fact that crops are still being affected by droughts and that fortified food crops are not a typical drought-adaptation measure per se. While they provide substantial benefits in improving the overall nutritional status of vulnerable people even under non-drought circumstances, they do not directly yield large additional food-security benefits under drought scenarios.

Overall, the Improving Food Security Pathway demonstrates that adaptation measures targeting information access, food preservation, and nutrition can substantially reduce drought-induced food insecurity while delivering strong economic returns. The results highlight three key messages: first, early warning systems and climate information services are highly cost-effective, as timely and widely disseminated information enables farmers and herders to reduce losses across a wide range of assets at relatively low cost; second, this pathway simultaneously protects both crops and livestock by supporting better production, storage, and management decisions during droughts; and third, post-harvest and preservation measures show strong scaling effects when supported by international investment, allowing many more households to safely store food for longer periods and substantially increasing avoided losses as droughts intensify. Together, these findings underscore the importance of prioritizing food security–focused measures that safeguard the availability, access, and affordability of food under a changing climate.

3.4 COMPARISON OF ADAPTATION PATHWAYS

This section compares the three adaptation pathways—Effectiveness, Food Security, and Green Sustainable Future—based on the assets they protect in Eastern Province, focusing on crops, livestock, and people under a severe climate change scenario (RCP 8.5). Using total averted damages and people protected as key metrics, the comparison highlights clear trade-offs and supports decision-making aligned with different policy priorities and budget levels.

In terms of crop protection, the Green Sustainable Future Pathway delivers the highest total avoided damages, particularly under international financing, with crop losses reduced by approximately USD 105 million, compared to USD 91 million under the Food Security Pathway and USD 69 million under the Effectiveness Pathway. Even under domestic budgets, the Green Sustainable Future Pathway slightly outperforms the others (Figure 27). These results reflect its strong focus on long-term, nature-based, and crop-focused measures—such as climate-smart agriculture, agroforestry, and drought-tolerant crops—that primarily benefit staple crops, especially maize, which dominates production and is particularly vulnerable to drought-related losses in the province. Since the Green Sustainable Future Pathway focuses solely on crop-related measures, its impact on reducing drought-induced crop damages outperforms the other Pathways. For policymakers prioritizing long-term crop resilience and protection of high-value or high-area crops, this pathway offers the strongest asset-based justification. Figure 27 compares the Pathways regarding crop protection benefits.

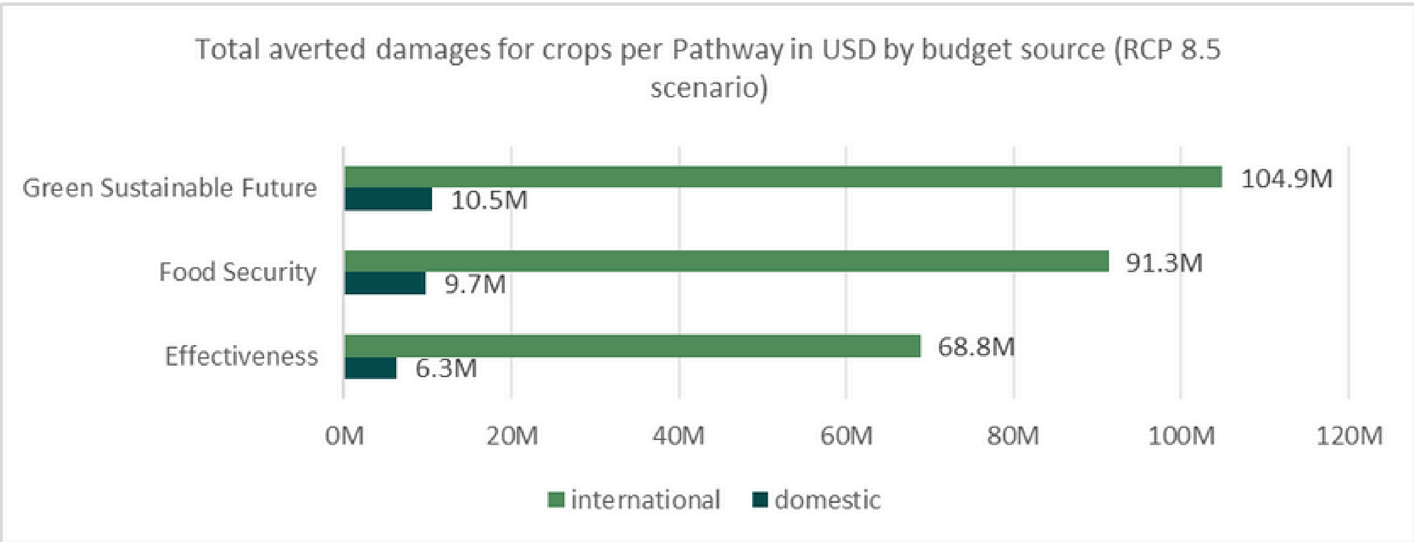


Figure 27: Total averted damages for crops (RCP 8.5)

Figure 28 shows a comparison of pathways regarding their potential to protect livestock. For livestock, the comparison is more limited, as only the Effectiveness and Food Security Pathways generate include measures targeting livestock. The Effectiveness Pathway clearly dominates, averting up to USD 56.5 million in livestock damages under international budgets, more than double the gains achieved under the Food Security Pathway (USD 23.5 million). Domestic investments show the same pattern, though at lower absolute levels. These results highlight that targeted, asset-specific interventions—such as locally adapted livestock breeds and direct drought risk reduction—are essential for protecting pastoral and mixed farming livelihoods. Where livestock losses are a major concern, the Effectiveness Pathway is the most suitable choice.

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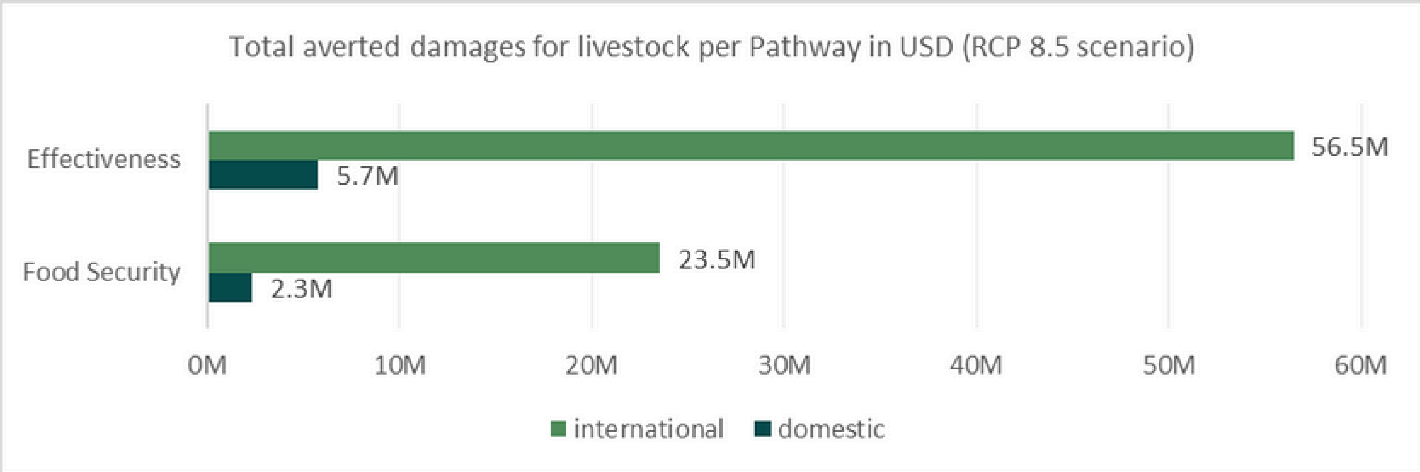

Figure 28: Total averted damages for livestock (RCP 8.5)

Figure 29 shows how the different pathways can reduce impacts for people. When considering people protected from drought-induced food insecurity, all three pathways perform strongly under international budgets, protecting around 313,000–330,000 people. Differences become more pronounced under domestic budgets: the Effectiveness Pathway protects the largest number of people (around 45,000), compared to roughly 32,000–33,000 under the Food Security and Green Sustainable Future Pathways. This reflects the strong immediate impacts of targeted measures under constrained funding, as well as the role of drought-tolerant crops and direct loss reduction in stabilizing food access. If the primary objective is to maximize human welfare impacts per dollar invested, particularly under limited fiscal space, the Effectiveness Pathway provides the strongest short-term returns.

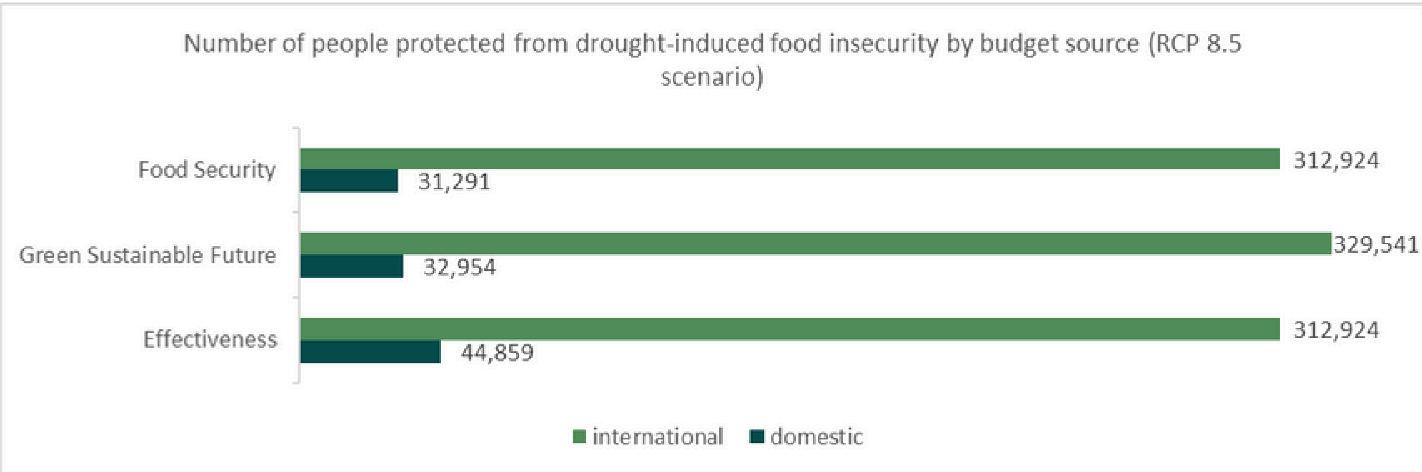

Figure 29: Total averted damages for People (RCP 8.5)

Overall, the comparison shows that no single pathway dominates across all asset classes, and pathway selection should be guided by clear priorities, for instance:

- Prioritize the Green Sustainable Future Pathway if the goal is to protect crop assets over the long term, especially maize, and to build structural resilience through scalable, nature-based solutions—particularly when international financing is available.
- Choose the Effectiveness Pathway when the priority is immediate and cost-effective protection of livestock and people, especially under domestic budget constraints and in areas with high exposure to drought-related asset losses.
- Adopt the Food Security Pathway where a balanced approach is desired, combining crop and livestock protection with social outcomes, particularly in programs explicitly targeting food and nutrition security outcomes alongside production. Due to its broad and balanced coverage, this Pathway can be considered an all-rounder.

From an action-oriented perspective, these results suggest that Eastern Province would benefit most from a sequenced or blended strategy: deploying the Effectiveness Pathway in the short term to protect vulnerable households and livestock, while scaling up Green Sustainable Future investments over time—especially with international support—to secure long-term crop resilience and sustained reductions in drought damages.

4.

CONCLUSION

4.1 EVALUATION OF POTENTIALLY SUITABLE FINANCING TOOLS AND MECHANISMS

Ensuring climate resilience in Zambia depends on the availability and accessibility of climate finance. Over the past decade, several mapping exercises have been undertaken in the country to identify the sources, instruments, mechanisms, and use of climate-related funds for both adaptation and mitigation. This study focuses specifically on adaptation finance. According to Zambia's 2021 Nationally Determined Contribution (NDC), an estimated USD 20 billion is required to implement the adaptation actions outlined in the document (Commonwealth Secretariat 2021)[WF1] . Complementing this, a 2023 study by the Potsdam Institute for Climate Impact Research (PIK), funded by GIZ, estimated adaptation finance needs based on the annual investment required for smallholder farmers to adopt recommended adaptation measures. Table 2 summarizes the adaptation measures and their estimated financing needs.

Table 2: Estimated Adaptation Measures financing needs (GIZ 2023)

Adaptation Measures	Estimated financing needs in USD p.a
Conservation agriculture, including water availability	19.9 – 35.7 million
Conservation agriculture, including water availability proxied by irrigation	267 million
Strengthening of early warning systems	719,000 – 29 million

The current study by UNU-EHS proposes two types of investments for the Adaptation Pathway, namely domestic investment scenarios and international investment scenarios. The domestic investment scenario requires USD 6 million to fully finance and maintain one Adaptation Pathway in one province until 2050. The international investment scenario is 10 times that of domestic financing, which amounts to USD 60 million. This sub-chapter will provide a brief introduction to possible climate financing sources, historical climate finance accessed by Zambia, and other potentially suitable financing tools and mechanisms.

Climate finance can originate from four broad sources: domestic public, domestic private, international public, and international private. While the private sector remains an important—yet largely untapped—source of climate finance, public sector contributions remain dominant. In fact, 92% of climate finance flows in Zambia come from public sources (African Development Bank Group 2023). For this reason, our analysis concentrates primarily on public finance.

Domestic public finance comprises government resources allocated to mainstream climate priorities across short-, medium-, and long-term development plans. In Zambia, these resources are mobilized through government revenue (tax and non-tax revenues, and earnings from state-owned enterprises) and domestic borrowing (government securities and bonds). Data for this assessment were gathered from the Ministry of Finance and National Planning, Bank of Zambia, Zambia Revenue Authority, and other relevant institutions. Figure 30 illustrates Zambia's overall resource envelope from 2010 to 2021 for development finance in general. Over this period, domestic revenues averaged roughly 19% of GDP. Beginning in 2015, domestic financing nearly doubled, averaging 5.1% of GDP between 2016 and 2021.

This trend continues until 2024, in which the percentage of domestic financing out of total climate change investment reached 40.1% (Crivellaro 2024). In contrast, international financing declined sharply after 2019, largely due to Zambia's debt being categorized as unsustainable by the IMF and World Bank, which contributed to negative investor sentiments (Zambia Institute for Policy Analysis and Research 2023).

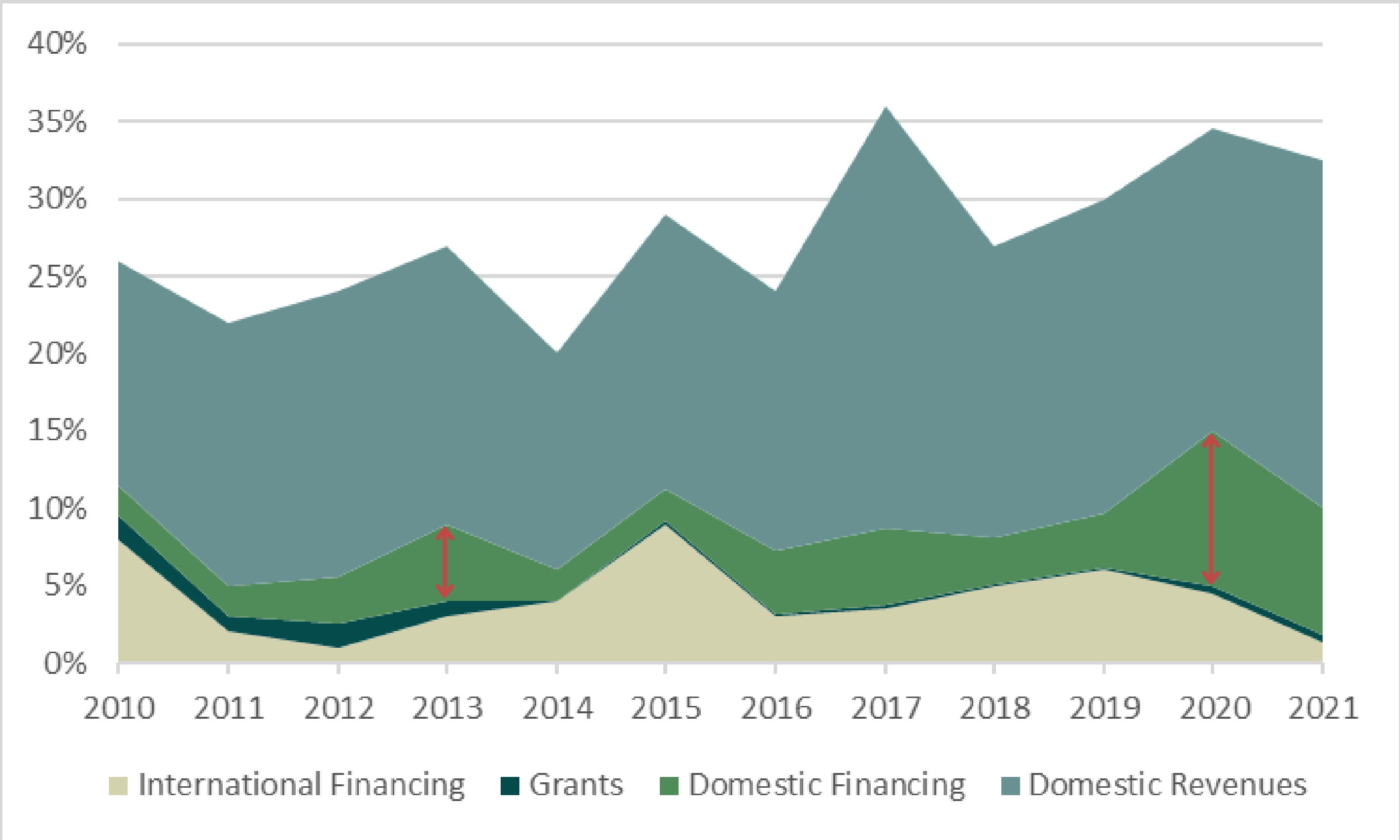

Figure 30: Zambia's resource envelope (reproduced from ZIPAR 2023)

International public climate finance includes bilateral, multilateral, and other development partners that provides resources through Official Development Assistance (ODA) and diverse financial instruments such as grants, concessional and non-concessional loans, guarantees, insurance products, and equity. These funds can be accessed through multiple mechanisms, including multilateral climate funds, sectoral funds, and multilateral development banks (MDBs). Major sources of multilateral grant financing in Zambia include the African Development Bank, the World Bank, IFAD, and the Global Fund.

Table 3 presents a summary of international public financing for adaptation that Zambia has accessed in recent years, categorized by bilateral and multilateral institutions, with multilateral sources further distinguished between UNFCCC and non-UNFCCC financing mechanisms.

Table 3: Zambia International Public Financing from 2017-2020 (Zambia Institute for Policy Analysis and Research 2023; GCF 2025; GEF 2025; Adaptation Fund 2024)

Bilateral institutions		
Country	Implementing agencies	Funds accessed 2017-2020 (in million USD)
United States of America	USAID	472.85
Germany	IKI/BMZ/GIZ/KfW	176.92
Sweden	SIDA	48.25
Japan	JBIC/JICA	35.71
United Kingdom	DEFRA/FCDO	24.76
China		21.72
Finland		11.23
Saudi Arabia		10.04
Denmark	DIHR	9.42
Ireland		7.29
France	AFD	0.47
Multilateral Institutions		
Financial Mechanisms	Agencies/climate funds	Funds accessed 2017-2020 (in million USD)
Non-UNFCCC financial mechanisms	World Bank	152.33
	IBRD	41.95
	European Union	20.21
	Global Fund	19.99
	IFAD	17.98
	ADF	14.58
	AfDB	13.45
	United Nations	3.01
	OPEC	2.78
	SADC	1.22
	CCARDESA MDTF	0.04
Financial Mechanisms	Dedicated climate funds	Funds accessed (# of projects) (in million USD)
UNFCCC financial mechanisms	GEF	459.1 (47 projects)
	GCF	146.8 (10 projects)
	LDCF	26.7 (4 projects)
	AF	14.0 (1 project)*

** Regional project with Malawi, with Pre-concept Endorsed submitted on 3 June 2025*

During the Biden administration, the United States provided nearly USD 600 million in annual development assistance to Zambia. The funds reflected in Table 3 cover only the 2017–2020 period; however, the recent cuts to USAID under the Trump administration introduce uncertainty regarding the future trajectory of U.S. bilateral support. In response, President Hichilema has acknowledged this shift and outlined a strong agenda to enhance domestic resource mobilization (Kamwengo 2025). This change in the global funding landscape also presents an opportunity for European partners, such as Germany, to reaffirm their long-standing development cooperation with Zambia. As of 2025, GIZ Zambia manages 12 commissioned projects with a total budget of EUR 141 million (GIZ 2025).

The World Bank has recorded 241 projects in Zambia through 2025, with 32 projects scheduled to close in 2026 or later, representing a combined project cost of USD 3.7 billion. Of this total, approximately 17% is allocated to Adaptive Social Protection initiatives, which aim to safeguard poor and vulnerable households from climate-related shocks. A further 16% supports energy-sector investments, 13% targets agricultural development, and 11% goes to the education sector (World Bank Group 2025).

An investment highlight is the second phase of the Transforming Landscapes for Resilience and Development (TRALARD II) project, which aims to strengthen the sustainable management of more than 680,000 hectares of land and enhance the livelihood resilience of over 650,000 people across vulnerable communities in Zambia's Miombo ecoregion. TRALARD II is financed through a blend of resources, including an IDA grant of USD 100 million, GEF financing of USD 3 million, LDCF support of USD 7 million, USD 10 million from the Africa Climate and People Trust Fund, USD 10 million from Strategic Climate Fund/Climate Investment Fund, and USD 7 million from the Scaling Climate Action by Lowering Emissions Multi-Donor Trust Fund.

Under the Green Climate Fund (GCF), the Ministry of Green Economy and Environment serves as the National Designated Authority. The Development Bank of Zambia (DBZ) and Zambia National Commercial Bank PLC (ZANACO) are accredited entities with direct access. Between 2018 and 2025, Zambia implemented a major GCF-supported initiative targeting smallholder farmers across five provinces: Eastern, Lusaka, Muchinga, Southern, and Western. The programme focuses on expanding access to climate information services, promoting climate-resilient agricultural inputs and practices, strengthening sustainable water management, and supporting alternative livelihood opportunities.

A new source of financing has recently become available to developing countries experiencing irreversible climate impacts: the Fund for Responding to Loss and Damage (FRLD) under the UNFCCC financial mechanisms. Agreed at COP27 in Sharm El Sheikh, the FRLD established a 26-member Board in 2023, with the Philippines serving as host in 2024 and the World Bank designated to host both the Secretariat and the Fund Trustee. Zambia is represented on the Board by David Chama Kaluba, the National Coordinator of the Zambia Interim Secretariat for Climate Change under the Ministry of Finance. The Board has approved the establishment of the Barbados Implementation Modalities (BIM) for the period 2025-2026, allocating USD 250 million to address loss and damage. Table 4 summarizes key information related to the BIM call for funding request.

Table 4: Barbados Implementation Modalities Call for Funding Request

Eligibility	**Developing countries that are particularly vulnerable to the adverse effects of climate change**
Submission period	15 December 2025 – 15 June 2026
Submission entity	National authority/focal point (including entities accredited for AF, GEF, GCF)
Budget	Between USD 5 million to USD 20 million
Implementation	Beyond 2026
Eligible activities	· Activities responding to economic and non-economic loss and damage · Activities focused on priority gaps
Link	https://www.frld.org/nodebim

To access additional adaptation financing, Zambia will need to strengthen its domestic resource base, including through the creation of fiscal buffers. This can be achieved by enhancing general revenue mobilization, such as through environmental taxes that both generate resources and incentivize greener behavior. At the same time, Zambia must attract a balanced mix of public and private investment. This includes leveraging innovative and emerging financial instruments such as green bonds, sustainable debt financing, debt-for-climate or debt-for-nature swaps, blended finance, and carbon markets. Table 5 provides further detail on these instruments.

Table 5: Innovative and Emerging Financial Instruments for Zambia (African Development Bank Group 2023; BIOFIN 2024; GWP 2025)

Instrument type	Green bonds, sustainable debt financing	Debt-for Climate/Nature Swaps	Blended Finance	Carbon Markets
Definition	Debt instruments where proceeds are allocated to eligible environmental and social projects or a combination of both	Debt forgiveness on the condition that debt repayments are instead invested in local currency and into climate change adaptation and mitigation	Instruments that use public/donor finance to de-risk and scale up private climate investments	Finance generated through investment in projects that reduce GHG emissions. Purchased by corporates or international actors to reduce or offset their CO2 footprint
Progress	0.1% of global green bond issuance. Issued in 9 countries with 3 countries accounting for over 90%.	New instrument and there is a need for high level dialogue with Zambian authorities and coordination with international climate funds to use it.	Leading globally (average USD 1.5 billion) per year. Most transaction concentrated in 5 countries.	11% of total carbon credits generated originate from Africa (Global market USD 2 billion). Zambia currently taking a readiness review.
Use case	Zambia's Copperbelt Energy Corporation Renewables issued first-ever green bond in 2023 valued at USD 53.5 million and in 2024 issued the second tranche valued at USD 96.7 million	Zambia is yet to prepare for the use of this instrument. Good potential for ADF resources to de-risk private sector financial flows	Zambia received GCF funding to develop a blended financing platform for Zambia Water Investment Programme with a total budget of USD 6 billion. Africa Go Green Fund, Acumen Fund, African Green Bank Initiative.	Africa Carbon Markets Initiative. Zambia has prepared interim regulatory guidelines. Zambia has been a net carbon sink, due to the large forest land area.
Estimated potential	Since 2023, in total USD 150.2 million	Zambia received a "debt-for-nature swap" proposal as part of its USD 13 billion debt restructuring discussions from the World Wildlife Fund	High leverage ratios (5-10 times public finance)	Still at a nascent stage

To complement Zambia's existing climate finance landscape, a number of regional flagship initiatives and thematic funds offer additional opportunities to mobilize adaptation and resilience financing. These mechanisms—ranging from multilateral trust funds to blended finance platforms and insurance facilities—could significantly enhance Zambia's ability to scale climate action across sectors. Table 6 provides an overview of these key initiatives and the potential entry points they offer.

In summary, Zambia's ability to scale adaptation action will depend on its success in mobilizing a diverse and well-coordinated mix of domestic and international financing. While domestic public resources and established multilateral institutions such as the World Bank, GEF, and GCF remain essential pillars, the newly established Fund for Responding to Loss and Damage (FRLD) and the Barbados Implementation Modalities (BIM) create additional opportunities to address irreversible climate impacts. Strengthening fiscal space and improving revenue mobilization will be crucial for expanding domestic public financing. Meanwhile, innovative external financing options, such as sustainable debt instruments, debt-for-climate or debt-for-nature swaps, blended public–private finance, and carbon markets, can help Zambia tap into broader sources of capital. At the same time, Zambia can benefit from a wide array of Africa-focused initiatives, including AAAP and AGIA, as well as risk-financing programs and SME catalytic funds, which provide targeted support across agriculture, water, infrastructure, and community resilience. Together, these tools and mechanisms provide a robust foundation for Zambia to advance a more climate-resilient development Pathway, provided they are strategically coordinated and aligned with national adaptation priorities.

Table 6: African Flagship Climate Initiatives/Funds and Relevance for Zambia (African Development Bank Group 2025)

Initiative/Fund	Key Features	Funding size/mechanism	Relevance to Zambia's Pathway
Africa Adaptation Acceleration Program (AAAP)	Mobilizes large-scale financing for adaptation through four pillars: (i) climate-smart digital technologies for agriculture and food security; (ii) infrastructure resilience accelerator; (iii) youth entrepreneurship and job creation in climate adaptation and resilience; (iv) innovative finance for adaptation.	Target of USD 25 billion, including USD 7 billion for resilient infrastructure and USD 3 billion for youth-led SMEs.	Major opportunity for agriculture, infrastructure resilience, and youth empowerment.
Adaptation Benefits Mechanism (ABM)	Results-based payment mechanism to mobilize public and private finance for resilience of vulnerable communities and ecosystems.	Results-based finance; size varies by project.	Supports vulnerable communities and ecosystems' resilience
Africa Climate Change Fund (ACCF)	Multi-donor trust fund providing small grants to African governments, NGOs, and regional institutions; gender-responsive and low-carbon development.	USD 40.64 million; 33 projects in 43 countries.	Potential small-grant window for adaptation planning or pilot interventions.
African Financial Alliance on Climate Change (AFAC)	Supports African financial institutions to integrate climate risks and mobilize private climate finance; capacity-building for SMEs.	Technical assistance and capacity development.	Helps strengthen Zambia's financial sector and SME climate investment readiness.
Africa Disaster Risk Financing (ADRiFi) Program	Works with African Risk Capacity (ARC) to promote sovereign parametric climate/disaster insurance.	Grant financing to Zimbabwe, The Gambia, Madagascar, Niger and Mauritania total investment USD 30 million	Zambia has not accessed it yet; potential for drought/flood risk financing.
African Water Facility	Supports climate-resilient water and sanitation investments through technical and financial assistance.	Grants EUR 50,000–5 million.	Relevant for water security, sanitation, and climate-resilient infrastructure.
Agri-food SME Catalytic Financing Mechanism Special Fund (AHFR)	AfDB–Canada blended finance facility targeting climate-resilient agri-food SMEs.	USD 85 million blended finance.	Opportunity to scale private investment in agri-SMEs and value chains.
Africa Climate Risk Insurance Facility for Adaptation (ACRIFA)	Develops climate risk insurance solutions for agriculture, adaptation, and resilience.	Aims to mobilize USD 1 billion in high-risk capital and grants.	Can expand insurance coverage for farmers and agribusinesses.
Alliance for Green Infrastructure in Africa (AGIA)	Develops bankable green infrastructure projects; blended finance and project-preparation support.	USD 100 million for preparation; USD 400 million blended fund; leverages USD 10 billion private investment.	Supports green infrastructure pipeline development and financing in Zambia.
Canada–African Development Bank Climate Fund (CACF)	Concessional loans for mitigation and adaptation with strong gender focus.	CAD 122.9 million repayable + CAD 10 million technical assistance grants.	Attractive for gender-responsive climate investments.
ClimDev Africa Special Fund	Joint AU–UNECA–AfDB initiative; supports climate information, hydromet services, and data systems; expanding via Systemic Observations Financing Facility (SOFF).	SOFF trust fund: USD 400 million.	Highly relevant for early warning systems and climate information services.
African Green Banks Initiative	Builds a network of African green banks to mobilize public and private climate investment aligned with NDCs.	Leverages blended finance and private capital (size not fixed).	Can help Zambia develop a green finance ecosystem and pipeline.

4.2 LIMITATIONS AND UNCERTAINTIES

The CLIMADA-based drought risk and adaptation analysis for Zambia's agricultural sector provides a consistent, comparative view of risk and of the potential benefits of selected measures across the focus provinces and scenarios. However, the results are subject to several limitations and sources of uncertainty that should be considered when interpreting the findings, the Adaptation Roadmaps and the results visualized in the Power BI platform. The analysis should be understood as indicative and comparative under defined assumptions, rather than as a detailed implementation plan or a precise forecast.

Model assumptions and implementation conditions of measures

The analysis assumes that the considered adaptation measures are implemented as specified and that they function as intended throughout the analysis period. This includes implicit assumptions about coverage, technical performance, and basic maintenance. In practice, delays in implementation, partial or uneven coverage across communities, limited maintenance, as well as program discontinuation can substantially reduce realized benefits. Behavioral factors (e.g. adoption and correct use of drought-tolerant seed varieties, uptake of climate-smart practices, timely response to early warnings) may further strengthen or weaken effectiveness but are not explicitly modelled. The reported risk reductions should therefore be interpreted as contingent on these idealized implementation and performance assumptions.

Spatial and sectoral resolution of the drought risk analysis

CLIMADA operates on gridded hazard and exposure data at an aggregated spatial resolution. Crops, production systems and adaptation measures are represented using available spatial information (e.g. district or ward-level statistics, land-use data, or proxy layers) and parameterized at grid-cell or area level, rather than as detailed, field-scale farm systems. This simplification is particularly relevant where smallholder plots are fragmented and heterogeneous, where local water availability depends on micro-catchments and soils, and where measure effectiveness depends strongly on local conditions. At this resolution, localized benefits and losses may be under- or overestimated.

Scenario and projection uncertainty

All future drought and risk estimates rely on climate and socio-economic scenarios that are inherently uncertain. The selected scenarios represent plausible, internally consistent futures, but they cannot capture the full range of possible trajectories in emissions, regional rainfall patterns, land use, demographic and market dynamics, or governance conditions. Risk estimates should therefore be seen as scenario-conditional outcomes, not precise predictions, particularly when comparing across time horizons and socio-economic pathways.

Data availability, exposure representation and calibration challenges

The reliability of risk estimates depends strongly on the underlying data on exposure and vulnerability. In many contexts, detailed, up-to-date information on crop types and management practices, farm sizes, and yield variability is limited. As a result, several elements of the exposure dataset rely on proxies and generalizations. Damage (impact) functions for agricultural losses under drought are based on a combination of literature, regional experience and expert judgement, with limited local loss data available for systematic calibration.

These constraints introduce uncertainty into absolute loss levels; the analysis is typically more robust for relative comparisons (between regions, scenarios, or portfolios) than for any single absolute estimate.

Adaptation portfolios and interactions between measures

The project assesses “adaptation portfolios”, i.e. bundles of measures implemented together. The model does not explicitly capture interaction effects between measures within a portfolio (synergies, diminishing returns, sequencing dependencies, or operational constraints). Portfolio results should therefore be interpreted as indicative, and differences between portfolios—especially where they share measures—should be treated with appropriate caution.

Budget assumptions and financing realism

The analysis considers two illustrative budget options to explore sensitivity to resource availability: a domestic budget of USD 1 million every three years and an international budget of USD 10 million every three years. These budgets are not predictions or commitments and are not intended as final costing envelopes. They are stylised examples for scenario exploration. In practice, available resources, disbursement schedules, co-financing, procurement and absorption capacity, and the timing of expenditures can differ substantially from these assumptions. Results linked to these budget options should therefore be read as conditional on the assumed envelopes and periodicity.

Uncertainty quantification and remaining structural uncertainty

Where uncertainty ranges are presented, they reflect variability in key input components such as hazard intensity, exposure values or vulnerability parameters. However, these intervals do not fully capture structural model uncertainty, such as alternative drought indices and impact models, different representations of cropping systems and livelihoods, or alternative vulnerability frameworks. Nor do they encompass deep uncertainties in future governance or macro-economic conditions that can strongly influence exposure and adaptive capacity. Reported uncertainty ranges should therefore be interpreted as lower-bound estimates of the full uncertainty.

Static exposure, vulnerability and behavioral assumptions

In the current setup, exposure and vulnerability are treated as static within each scenario horizon, aside from scenario-based adjustments. The model does not dynamically simulate shifts in cropping patterns or varieties, expansion of irrigation, improvements in extension services, or changes in market access and farm structure. Given demographic and economic change, this simplification may lead to under- or overestimation of future risks and of the long-term benefits of adaptation.

Non-economic outcomes and excluded co-benefits

The project includes food security-relevant outputs and non-economic representations for certain assets by reporting impacts both in monetary terms and in physical quantities (e.g. livestock expressed as USD and as heads). However, several important outcomes and co-benefits remain outside the model scope or are not quantified, including:

- gender and distributional outcomes within households and communities;
- migration and displacement dynamics;
- ecosystem services and environmental externalities (e.g. biodiversity, groundwater recharge, long-term soil regeneration);
- broader institutional and social cohesion effects.

Interpretation and appropriate use of results

Taken together, these limitations imply that the outputs should be interpreted as indicative and comparative rather than as precise forecasts. The analysis is well-suited to compare the relative performance of measures and portfolios, explore robustness across scenarios, and support strategic discussion on where additional assessment, data collection or piloting is most valuable. Results should be used alongside local knowledge and implementation experience. Future work could prioritise improved local agricultural data, Zambia-specific calibration of impact functions, exploration of dynamic exposure and adoption pathways, and more systematic treatment of distributional and ecosystem-related outcomes.

Crop Impact Modelling Approach and Data Constraints

CLIMADA is not a crop growth or yield model; instead, it is used to quantify the impacts of climate change on crop production and related monetary losses. Crop impacts are estimated using historical observations of crop damage during drought years, which are used to calibrate impact functions linking drought intensity to the degree of crop damage. Within the probabilistic modelling framework, crop-specific production trends, annual growth rates, and documented losses during past drought events inform the estimation of future impacts. As a result, simulated crop damages reflect observed historical relationships and are constrained by the availability, consistency, and quality of data on crop production and losses.

Risks of Maladaptation

While this report demonstrates the strong potential of targeted adaptation measures to reduce drought-related damages, it is important to acknowledge the risk of maladaptation if interventions are poorly designed or implemented without sufficient local context. Maladaptation occurs when actions intended to reduce climate vulnerability instead increase exposure or sensitivity to climate risks. In livestock systems, for example, the promotion of high-yielding exotic breeds can unintentionally increase vulnerability to heat stress and disease if these breeds lack locally adapted traits. Similarly, land-use interventions that restrict mobility—such as the expansion of irrigated agriculture into dryland areas—can undermine pastoral and agropastoral systems that depend on seasonal access to water and grazing resources. These dynamics are not fully captured in quantitative modelling and highlight the need for context-specific feasibility studies before implementation, ensuring that adaptation measures align with existing livelihood strategies and do not erode coping mechanisms that have evolved over time.

Gender and Social Dimensions

Another key source of uncertainty relates to gender and social differentiation, which are not explicitly modelled in this assessment. Women and men play different roles in crop and livestock production, have unequal access to resources, and experience climate risks differently. Women often have lower adaptive capacity due to limited access to finance, land, information, and extension services, yet they are heavily involved in livestock and farm management. Interventions that do not explicitly consider gender roles can inadvertently increase women's labor burdens or exclude them from benefits, particularly when programs prioritize formal markets or engage primarily with male household members. At the same time, women have significant potential to act as agents of innovation in climate adaptation if provided with targeted support. These complexities underline the importance of conducting gender assessments alongside feasibility studies to ensure that adaptation measures are equitable, effective, and socially sustainable, and that they strengthen the adaptive capacity of all members of rural households.

Local Adoption of Practices

The modelling has been implemented with the assumption that the suggested activities, such as Agroforestry, are implemented and maintained according to their definition. However, stakeholders emphasized several important considerations for the effective uptake of adaptation measures, including the need to understand the reasons behind farmers' limited adoption of climate-smart agriculture, the importance of strengthening farmer-to-farmer knowledge exchange, and the value of building capacity in ways that draw on existing experience and indigenous practices. They also emphasized the need to ensure broad stakeholder engagement to support the long-term ownership and sustainability of adaptation efforts. As the Roadmaps are implemented, these additional aspects—such as overcoming adoption barriers, establishing effective community training structures, ensuring inclusive decision-making, and integrating local knowledge—will need to be deliberately incorporated to achieve meaningful and lasting results.

4.3 KEY TAKEAWAYS AND WAY FORWARD

This report provides a comprehensive, forward-looking assessment of drought risk and adaptation options for Zambia's Eastern Province under moderate (RCP 4.5) and severe (RCP 8.5) climate change scenarios. It provides a quantitative foundation for climate adaptation planning in Zambia's Eastern Province. By combining drought risk modelling with an economic assessment of adaptation options under different climate and budget scenarios, it moves beyond qualitative vulnerability assessments and demonstrates where and at what scale drought risks impact assets in a monetary way, reduce production outcomes, and impact livestock and people. The analysis demonstrates that drought is not only a recurrent shock but a growing structural risk that threatens core production outcomes, livelihoods, and food security. It further quantifies how adaptation investments can reduce damages and protect livelihoods. The pathway-based approach applied here is not intended to prescribe a single solution, but rather to kick-start structured adaptation planning, offering an evidence base that can be refined, expanded, and operationalized over time. At the same time, the results clearly show that well-targeted adaptation investments—at both domestic and international budget levels—can substantially reduce damages, protect people, and strengthen long-term resilience.

Three adaptation pathways were assessed—Effectiveness, Improving Food Security, and Green Sustainable Future—not because they represent the only possible options, but because they capture distinct policy objectives and adaptation logics. This pathway-based framing allows decision-makers to explicitly link investments to priorities, such as effective economic loss reduction, people-focused approach, or nature-based long-term sustainability.

Importantly, the analysis confirms that different pathways protect different assets:

- The **Effectiveness Pathway** excels at protecting assets most at risk, such as cattle and maize, delivering immediate and cost-effective reductions in drought damages.
- The **Food Security Pathwa**y focuses on people, protecting both crops and livestock while reducing drought-induced food insecurity through information, storage, and nutrition-sensitive measures.
- The **Green Sustainable Future Pathway** is crop-focused, with benefits concentrated on maize and other key crops, and plays a critical role in building long-term resilience through soil, water, and ecosystem improvements.

No single pathway dominates cost-effectiveness across all assets. This reinforces the value of the pathway approach as a decision-support tool, rather than a one-size-fits-all solution.

Drought Risk and Vulnerable Assets

The drought risk assessment confirms that maize and cattle are the most vulnerable assets in the Eastern Province, reflecting both their central economic role and their high sensitivity to rainfall variability and drought intensity. Maize dominates total drought damages because it is the primary staple crop, cultivated over extensive areas, and closely linked to household food security and income. The total annual expected monetary losses are projected to be up to USD 74 million per year due to climate change for crops under the severe climate change scenario in 2050, with USD 47 million for maize. Under future climate conditions, particularly in the RCP 8.5 scenario, drought-related crop losses are expected to increase without adaptation, resulting in higher food insecurity and economic losses.

Livestock—particularly cattle—also face increasing risks through reduced pasture availability, water scarcity, and heat stress during drought years. Total annual expected monetary losses are projected to be up to USD 39 million per year due to climate change for livestock (cattle and pigs) under the severe climate change scenario in 2050. The analysis shows that without targeted adaptation, both crop and livestock systems become increasingly exposed as droughts intensify and occur more frequently.

Different Pathways, Different Strengths

A central insight of the report is that adaptation pathways, although based on the same budgets, are unique due to their different focuses: each pathway protects different assets and delivers benefits through distinct mechanisms. Policy choices should therefore be guided by clear priorities.

The Effectiveness Pathway delivers the highest and most immediate protection for livestock, particularly cattle, and generates strong benefits for crops as well. Under RCP 8.5, it achieves the largest avoided livestock damages (up to USD 56.5 million under the international budget) and performs strongly even under domestic financing. This pathway is especially suitable where protecting primary assets, such as cattle and maize, stabilizing rural livelihoods, and reducing high-risk drought losses are key objectives.

The Improving Food Security Pathway focuses on reducing drought-induced food insecurity, protecting both crops and livestock while delivering strong social and nutrition co-benefits. Measures such as early warning systems, climate information services, fortified food crops, and post-harvest storage protect large numbers of people at relatively low cost. This pathway consistently performs well across climate scenarios and is particularly effective in safeguarding vulnerable households and stabilizing food systems during drought years by promoting early warning systems and disseminating climate information.

The Green Sustainable Future Pathway is largely crop-focused, with benefits concentrated on maize and other key crops, and no direct benefits for livestock. This pathway plays a crucial role in building long-term resilience through improved soils, enhanced water retention, and increased ecosystem services. Climate-smart agriculture protects a wide range of crops simultaneously, while drought-tolerant crops reach the largest number of people by stabilizing staple food production. This pathway becomes increasingly important under severe climate change (RCP 8.5), where nature-based solutions show their strength over time.

Budgets Matter—but Action Can Start Now

Across all pathways and climate scenarios, the results reveal a clear and consistent pattern: increased investment yields higher absolute adaptation benefits. International budget scenarios enable scaling up interventions across more districts, households, and hectares, resulting in substantially higher avoided damages and more people protected from food insecurity. For example, depending on the Pathway selected, total avoided crop damages increase from USD 6-10 million under domestic budgets to USD 70-100 million or more under international financing in some pathways. Overall, B/C ratios under domestic and international budgets vary, with the Food Security Pathway showing larger B/C ratios for the domestic scenario than for the international scenario for averted damages for crops, while the other two Pathways, Improving Food Security and Green Sustainable Future, produce comparatively higher outcomes per USD invested under the international funding compared to the domestic budget scenario.

However, a critical and encouraging finding is that domestic investments achieve higher benefit–cost ratios for many adaptation measures. This means that every dollar spent domestically tends to deliver strong returns, especially when investments are focused on high-risk areas and highly vulnerable assets such as maize and cattle. Even relatively small national budgets already generate significant reductions in drought damages and food insecurity. In practical terms, this means that adaptation does not need to wait for large external funding—effective action can begin immediately.

Climate Change Scenarios Reinforce the Case for Adaptation

The comparison between the different climate change scenarios RCP 4.5 and RCP 8.5 clearly underscores that adaptation becomes more valuable as climate change intensifies. While some measures show modest returns under moderate climate change scenarios (RCP 4.5), their benefits increase markedly under severe climate change scenarios (RCP 8.5), particularly for climate-smart agriculture, agroforestry, early warning systems, and livestock-focused interventions. This reinforces the importance of planning not only for current risks, but for future climate extremes.

Way Forward: From Analysis to Implementation

This assessment should be viewed as a starting point for adaptation planning in the Eastern Province, rather than an endpoint. While three pathways were analyzed, many additional combinations and measures are possible, and future work can refine assumptions, include additional co-benefits, and expand sectoral coverage.

Key next steps include:

- Feasibility studies and piloting of priority measures identified under each pathway, particularly in high-risk districts.
- Integration into district and provincial agricultural and development plans, using the quantified results to support prioritization and sequencing of investments.
- Use of the results in climate finance applications, including proposals to the Green Climate Fund, Adaptation Fund, the Fund for Responding to Loss and Damage, or bilateral donors, where quantified avoided damages and people protected strengthen the investment case.

Overall, the findings send a clear and positive message: drought risk in the Eastern Province is increasing, but adaptation investment can offset damages and protect people. Targeted adaptation investments deliver strong returns under all climate scenarios, domestic budgets already make a difference, and larger investments unlock transformative opportunities. By using this pathway-based assessment as a foundation for planning, financing, and implementation, the Eastern Province can move decisively from risk assessment to action—building resilience, protecting livelihoods, and securing food systems in a changing climate.

5.

PUBLICATION BIBLIOGRAPHY

Adaptation Fund (2024): Proposal for Zambia. Available online at https://www.adaptation-fund.org/document/proposal-for-zambia-5/, checked on 12/2/2025.

African Development Bank Group (2023): Country Focus Report 2023. Mobilizing Private Sector Financing for Climate and Green Growth. Available online at https://www.afdb.org/en/documents/country-focus-report-2023-zambia-mobilizing-private-sector-financing-climate-and-green-growth?utm_source=chatgpt.com, checked on 11/11/2025.

African Development Bank Group (2025): Flagship climate initiatives and Funds. African Development Bank Group. Available online at https://www.afdb.org/en/cop30/flagship-climate-initiatives-and-funds#:~:text=The%20African%20Green%20Banks%20Initiative,in%20line%20with%20their%20NDCs., checked on 12/2/2025.

APHLIS (n.d.): Dry weight loss: Zambia - All crops - All years. Available online at https://www.aphlis.net/en/data/tables/dry-weight-losses/ZM/all-crops/all-years, checked on 12/2/2025.

BIOFIN (2024): Zambia announces US$ 96.7 Million Green Bond issue to expand renewable energy, leveraging BIOFIN-supported regulatory reforms. The Biodiversity Finance Initiative; UNDP. Available online at https://www.biofin.org/news-and-media/zambia-announces-us-967-million-green-bond-issue-expand-renewable-energy-leveraging, checked on 12/2/2025.

Bourgault, Pascal; Huard, David; Smith, Trevor James; Logan, Travis; Aoun, Abel; Lavoie, Juliette et al. (2023): xclim: xarray-based climate data analytics. In JOSS 8 (85), p. 5415. DOI: 10.21105/joss.05415.

Chavula, Petros; Mambwe, Hockings; Mume, Abduletif Abdurahman; Umer, Yusuf; Chazya, Wellington (2023): Impact of Agroforestry Adoption among Smallholder Farmers' Households in Zambia: An Expenditure Approach. In East Afr. j. for. agrofor. 6 (1), pp. 309–328. DOI: 10.37284/eajfa.6.1.1474.

Chigeza, Godfree; Boahen, Steve; Gedil, Melaku; Agoyi, Eric; Mushoriwa, Hapson; Denwar, Nicholas et al. (2019): Public sector soybean (Glycine max) breeding: Advances in cultivar development in the African tropics. In Plant Breeding 138 (4), pp. 455–464. DOI: 10.1111/pbr.12682.

Commonwealth Secretariat (2021): Climate Finance Mapping for NDC Implementation in Zambia. Commonwealth Secretariat. Available online at https://www.thecommonwealth-ilibrary.org/index.php/comsec/catalog/view/988/985/8347, checked on 11/13/2025.

Crivellaro, Pierpaolo (2024): Climate and Carbon Finance Mechanisms in Zambia. Gap Analysis and Corruption Risk Vulnerability Assessment. Transparency International Zambia. Available online at https://tizambia.org.zm/wp-content/uploads/2024/10/Climate-gap-analysis-report.pdf, checked on 11/11/2025.

Dzavo, Takunda; Zindove, Titus J.; Dhliwayo, Marshall; Chimonyo, Michael (2019): Effects of drought on cattle production in sub-tropical environments. In Tropical animal health and production 51 (3), pp. 669–675. DOI: 10.1007/s11250-018-1741-1.

Esterhuizen, D. (2024): Zambia Depends on Corn Imports to Maintain Food Security. USAID. Available online at https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Zambia%20Depends%20on%20Corn%20Imports%20to%20Maintain%20Food%20Security_Pretoria_Zambia_ZA2024-0001.pdf.

Food Security Cluster; WFP (2024): Food Security Cluster Joint Rapid Assessment Report, March 2024. Available online at https://reliefweb.int/report/zambia/food-security-cluster-joint-rapid-assessment-report-march-2024https://reliefweb.int/report/zambia/food-security-cluster-joint-rapid-assessment-report-march-2024, checked on 11/19/2025.

GCF (2025): Republic of Zambia. Available online at https://www.greenclimate.fund/countries/zambia, checked on 12/2/2025.Adaptation-2022_Livestock.pdf, checked on 11/27/2025.

GEF (2025): Zambia. Country-At-A-Glance. Available online at https://www.thegef.org/projects-operations/country-profiles/zambia, checked on 12/2/2025.

Gergel, Diana R.; Malevich, Steven B.; McCusker, Kelly E.; Tenezakis, Emile; Delgado, Michael T.; Fish, Meredith A.; Kopp, Robert E. (2023): Global downscaled projections for climate impacts research (GDPCIR): preserving extremes for modelling future climate impacts.

GIZ (2024): Post Harvest Management Practices Manual for Trainers. Available online at https://www.giz.de/en/downloads/giz2024-en-post-harvest-management-practices-training-manual-for-trainers.pdf.

GIZ (2025): Zambia. GIZ. Available online at https://www.giz.de/en/regions/africa/zambia, checked on 12/1/2025.

Global Center on Adaptation (2023): Livestock. Available online at https://gca.org/wp-content/uploads/2023/01/GCA_State-and-Trends-in-Adaptation-2022_Livestock.pdf, checked on 11/27/2025.

Global Centre on Adaptation (2022): State and Trends in Adaptation. Livestock. Available online at https://gca.org/wp-content/uploads/2023/01/GCA_State-and-Trends-in-Adaptation-2022_Livestock.pdf.

GWP (2025): Zambia Pursues Blended Financing to Unlock Water Investments, Seeks $6 Billion in Water Financing. Global Water Partnership Southern Africa. Available online at https://www.gwp.org/en/GWP-SouthernAfrica/About-GWP-SAF/more/News/zambia-pursues-blended-financing-to-unlock-water-investments-seeks-$6-billion-in-water-financing/, checked on 12/2/2025.

Hargreaves, George H.; Samani, Zohrab A. (1985): Reference Crop Evapotranspiration from Temperature. In Applied Engineering in Agriculture 1 (2), pp. 96–99. DOI: 10.13031/2013.26773.

IPC (2024): IPC ACUTE FOOD INSECURITY ANALYSIS. Zambia April 2024-March 2025. Available online at https://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/IPC_Zambia_Acute_Food_Insecurity_Jul2024_Mar2025_Report.pdf://reliefweb.int/report/zambia/zambia-ipc-acute-food-insecurity-analysis-april-2024-march-2025-published-2-october-2024.

Kamwengo, Cynthia (2025): Debating Trump 2.0 and Implications for Africa - Reality Check for Zambia: Resilience in the Face of US Aid Cuts? Stiftung Wissenschaft und Politik. Available online at https://www.swp-berlin.org/en/publication/mta-spotlight-46-reality-check-for-zambia-resilience-in-the-face-of-us-aid-cuts, checked on 12/1/2025.

Kontur (2022): kontur_population_NE_20220630.gpkg. Available online at https://geodata-eu-central-1-kontur-public.s3.amazonaws.com/kontur_datasets/kontur_population_NE_20220630.gpkg.gz.

Li, Lijuan (2019): CAS FGOALS-g3 model output prepared for CMIP6 CMIP. With assistance of Lijuan Li, Yongqiang YU, Li Dong, Jinbo Xie, Yanli Tang.

Microsoft Open Source; Matt McFarland; Rob Emanuele; Dan Morris; Tom Augspurger (2022): microsoft/PlanetaryComputer: October 2022: Zenodo.

Ministry of Foreign Affairs of Zambia (2/29/2024): DECLARATION OF DROUGHT AS A NATIONAL DISASTER AND EMERGENCY. Lusaka. Available online at https://www.mofaic.gov.zm/wp-content/uploads/2024/03/Statement-on-Drought-as-a-National-Disaster-and-Emergency-H.E.docx.pdf, checked on 11/19/2025.

Ministry of Technology and Science Zambia (n.d.): NISIR STARTS TRIALS ON DROUGHT RESISTANT CASSAVA AND SWEET POTATOES. Available online at https://www.mots.gov.zm/?p=3752, checked on 12/2/2025.

Motsa, Nozipho M.; Modi, Albert T.; Mabhaudhi, Tafadzwanashe (2015): Sweet potato (Ipomoea batatas L.) as a drought tolerant and food security crop. In S. Afr. J. Sci. 111 (11/12), p. 8. DOI: 10.17159/sajs.2015/20140252.

Mphande, Emelia; Umar, Bridget Bwalya; Kunda-Wamuwi, Chibuye Florence (2022): Gender and Legume Production in a Changing Climate Context: Experiences from Chipata, Eastern Zambia. In Sustainability 14 (19), p. 11901. DOI: 10.3390/su141911901.

Mpofu, J. (2023): Improved Groundnut Varieties. Zambia Climate Network. Available online at https://zambiaclimatenetwork.com/2023/08/23/improved-groundnut-varieties/, checked on 9/14/2025.

Mwape, Andrew; Hayes, Michael; Bathke, Deborah J.; Smith, Kelly Helm; Mahmood, Rezaul; Jones, Elizabeth (2025): Drought Management in Zambia: Insights from the 2023/2024 Drought. InClimate 13 (11), p. 227. DOI: 10.3390/cli13110227.

Nyirenda, Faindani (2024): Assessment of the Drivers of Adoption of Climate Smart Agriculture Practices Among Field Crop Farmers in Zambia. University of Zambia; University of Arkansas.

Pérez-Hoyos, Ana (2018): Global crop and rangeland masks. European Commission, Joint Research Centre (JRC) [Dataset] PID. Available online at http://data.europa.eu/89h/jrc-10112-10005.

Phiri, Elijah; Zimba, Simon (2018): Root-Zone Soil Water Balance and Sunflower Yield under Deficit Irrigated in Zambia. In OJSS 08 (01), pp. 61–73. DOI: 10.4236/ojss.2018.81005.

Pokhrel, Sameer; Kharel, Prasanna; Pandey, Swikriti; Botton, Stephanie; Nugraha, Gema Takbir; Holbrook, Corley; Ozias-Akins, Peggy (2024): Understanding the impacts of drought on peanuts (Arachis hypogaea L.): exploring physio-genetic mechanisms to develop drought-resilient peanut cultivars. In Frontiers in genetics 15, p. 1492434. DOI: 10.3389/fgene.2024.1492434.

Siamabele, Brivery; Manda, Simon (2024): Soyabean expansion and smallholder livelihoods in rural Zambia: dynamics, experiences and implications. In Cogent Food & Agriculture 10 (1), Article 2413402. DOI: 10.1080/23311932.2024.2413402.

Siatwiinda, Siatwiinda M.; Supit, Iwan; van Hove, Bert; Yerokun, Olusegun; Ros, Gerard H.; Vries, Wim de (2021): Climate change impacts on rainfed maize yields in Zambia under conventional and optimized crop management. In Climatic Change 167 (3-4). DOI: 10.1007/s10584-021-03191-0.

The Economist Intelligence Unit: Real GDP (% change pa). Available online at https://viewpoint.eiu.com/data/results?searchId=c7989395-73c2-4efb-9c3a-24705f015f66, checked on 10/31/2025.

The Zero Hunger Coalition (2024): Solutions for reducing post-harvest losses in Zambia. Available online at https://www.zerohungercoalition.org/en/solutions-reducing-post-harvest-losses-zambia.

United Nations, Department of Economic and Social Affairs, Population Division (2025): World Population Prospects 2025, Online Edition.

Vicente-Serrano, Sergio M.; Beguería, Santiago; López-Moreno, Juan I. (2010): A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. In Journal of Climate 23 (7), pp. 1696–1718. DOI: 10.1175/2009JCLI2909.1.

World Bank Group (2025): Zambia. World Bank Group. Available online at https://www.worldbank.org/en/country/zambia, checked on 12/2/2025.

Zambia Institute for Policy Analysis and Research (2023): Development Finance Assessment for Zambia. UNDP. Available online at https://sdgfinance.undp.org/resource-library/development-finance-assessment-zambia?, checked on 11/11/2025.

6.

TECHNICAL APPENDIX

METHODOLOGY - CLIMATE RISK & ADAPTATION ROADMAP PROCESS

What This Annex Provides

This Technical Annex presents the full methodological foundation for the drought risk and adaptation assessment conducted in Zambia's Eastern and Southern Provinces, following the Economics of Climate Adaptation (ECA) Framework and operationalized using the CLIMADA probabilistic risk modelling platform. It provides complete transparency regarding analytical decisions, data sources, model parameters, and assumptions, ensuring scientific traceability and reproducibility.

The annex documents the participatory modelling process used to define exposed assets, collect and validate local data, and integrate stakeholder-derived priorities into the analytical workflow. It outlines the procedures for asset localization and valuation, the development of drought-specific damage functions, and the integration of climate hazard projections and socioeconomic growth assumptions. The risk assessment methodology combines hazard, exposure, and vulnerability layers to estimate present and future drought impacts at high spatial resolution.

For the adaptation assessment, the annex outlines the development of a long list of adaptation measures, the criteria-based ranking of options, the formulation of adaptation pathways, and the quantification of measure-specific impacts and costs. It further describes the preparation of CLIMADA entity files, the design of domestic and international investment scenarios, and the spatial allocation of measures based on drought hotspot analysis. These inputs enable the calculation of avoided damages, cost–benefit ratios, and the comparative performance of adaptation pathways through 2050.

Overall, this annex serves as both a comprehensive disclosure of the methodology applied in this study and a technical guide for practitioners seeking to replicate or extend ECA/CLIMADA-based climate risk and adaptation analyses in Zambia or similar contexts.

I. INTRODUCTION - BACKGROUND ON PARTICIPATORY MODELLING

This technical annex provides a detailed description of the methodology of this study. Based on the Economics of Climate Adaptation (ECA) Framework for implementing the CLIMADA risk and adaptation modelling, data were researched, compiled, and prepared as inputs for modelling. In this process, stakeholder involvement played a key role, as local experts bring unique knowledge and perspectives. This participatory modelling approach enabled the inclusion of stakeholder perspectives at all stages of the process, from shaping the scope of the analyses in the two different provinces by prioritizing key assets, including validated cost estimates, to ranking final pathway options.

Stakeholder involvement is crucial to ensure that the analysis accurately reflects local realities, addresses power imbalances in knowledge production, and fosters ownership of the results. Climate risk modelling is often dominated by global or external expertise, which can overlook context-specific insights from local, indigenous, and provincial actors. By embedding participatory processes throughout the study, the project aimed that the resulting pathways are not only technically sound but also socially legitimate and relevant for decision-makers in Zambia. To achieve this, experts were engaged through in-person workshops, hybrid webinars, and targeted consultations. Two local consultants—one for each province—were hired to bring an in-depth understanding of local livelihoods, farming systems, and institutional dynamics. Additionally, questionnaires were shared with a broader expert community to validate assumptions, estimate costs, and prioritize adaptations. Throughout the entire process, particular attention was paid to treating the Eastern and Southern Provinces separately, recognizing their distinct agricultural systems, climate challenges, and livelihood contexts. This approach enabled the model to capture the diversity of local experiences and support the development of adaptation pathways grounded in the specific needs and priorities of each province.

The purpose of this technical annex is to provide full transparency on the analytical steps, data choices, and assumptions applied throughout the study. It serves as a comprehensive guiding document that allows readers to understand, replicate, or adapt the methodology for future work in Zambia or similar contexts. By documenting each phase of the process in a clear, systematic, and scientifically robust manner, the annex reflects the traceable scientific workflow that can be repeated or expanded by government partners, research institutions, or development organizations. The annex is structured into six main subchapters, each of which outlines the detailed procedures, data sources, model parameters, and decision criteria used.

The ECA Framework and the CLIMADA Modelling Tool

The Economics of Climate Adaptation (ECA) framework is applied to enhancing climate governance in Zambia through a risk assessment approach that addresses climate impacts. By incorporating data on exposed elements, adaptation measures, and regional priorities, the framework supports the development of adaptation and risk-financing strategies. This integration ensures that a thorough understanding of risks, impacts, and the effectiveness of the adaptation measures informs decision-making to more resilient and sustainable development planning.

Through the application of the ECA framework, the aim is to provide decision-makers, including the local governments at various levels, as well as relevant stakeholders, with information and further capacity on:

- What impacts can be expected from drought hazards in the coming decades, based on the latest climate projection models?
- To what extent can various adaptation measures implemented at different levels reduce the expected impacts in the coming decades?
- What will be the cost of implementing suitable adaptation measures?
- Which measures are the most cost-effective for reducing the expected impacts?
- How can decision-makers use the results to target strategic adaptation and development plans, and which financial mechanisms/ sources might be most suitable?

The outcomes of the ECA study include evaluating the potential climate-related damages projected for the coming decades and determining how various measures can mitigate these damages. Additionally, the framework assesses the investments needed to implement these measures. It compares them to the benefits of avoiding damage from extreme events, ensuring that the reduction in damages justifies the investments (cost-benefit analysis). Ultimately, the ECA Framework provides a comprehensive and systematic approach to assessing climate threats and identifying cost-effective adaptation solutions. CLIMADA is the modelling platform used in implementing the ECA methodology ("Modelling Phase"). It enables probabilistic climate risk modelling to evaluate the exposure, vulnerability, and impact on assets and conducts cost-benefit analyses to compare different adaptation measures. By linking future climate scenarios with the developed exposure and vulnerability data, CLIMADA calculates location-specific damages for the defined asset categories. These outputs, combined with the impacts of the adaptation measures, generate the cost-benefit analysis of adaptation measures.

The data collection strategy for this project focuses on convening and validating high-quality data needed to perform climate risk assessments, specifically for drought events, as well as assessing historical records on impacts, asset values, and adaptation needs for the Eastern and Southern provinces. Data gathering will be anchored in existing sources and collaborative stakeholder engagement, ensuring that local knowledge and datasets are considered, validated, and integrated into the CLIMADA model. This will be achieved by engaging and collaborating with local consultants from the Ministry of Fisheries and Livestock and the Ministry of Agriculture of the respective regions. This approach will maximize the results' relevance, accuracy, and utility.

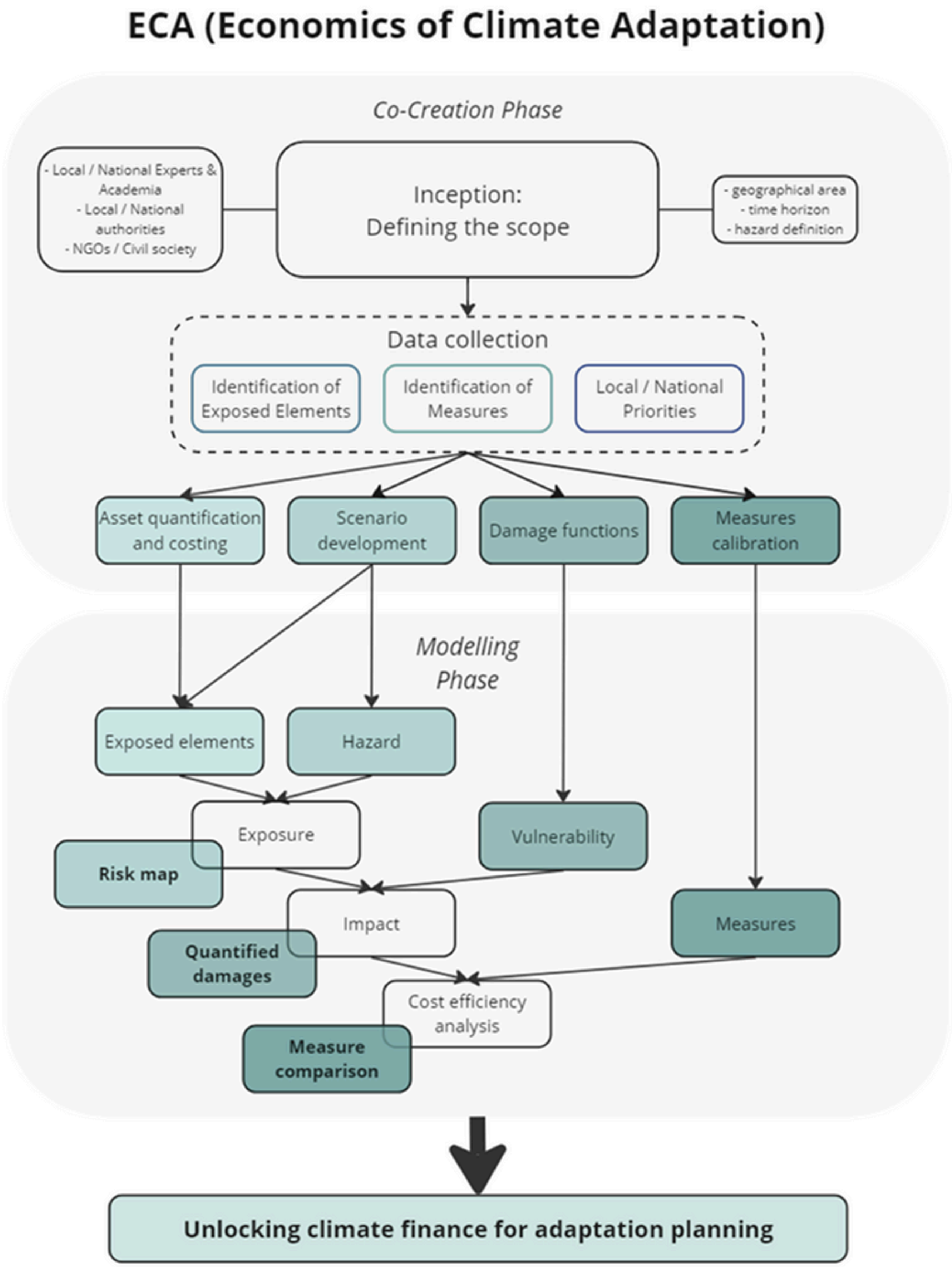

Figure 31: The ECA Framework and its participatory modelling approach

II. PROJECT INITIATION & SCOPING

This section summarizes the methodology used to identify and select the assets that form the basis of the drought risk analysis for the Eastern and Southern Provinces. To target the scope of the risk assessment, defining the elements exposed to drought risks constitutes the first step. These exposed elements, also referred to as assets in the ECA/CLIMADA context, need to be identified and valued in collaboration with experts, who bring knowledge about local priorities for the risk assessment.

The process began with an initial brainstorming during the **Inception Workshop**, where participants contributed region-specific suggestions based on their local experience and expertise. This preliminary list was then expanded and refined through an in-depth **literature review** and analysis of quantitative datasets to ensure statistical relevance and alignment with existing evidence. To further ground the selection in local realities, online **questionnaires** were distributed to a broader group of stakeholders, focusing particularly on how drought impacts different assets and how vulnerable population groups are affected. The insights from these steps were then consolidated into an **Asset Prioritization Survey**, completed by provincial experts, which ultimately informed the final set of assets included in the study.

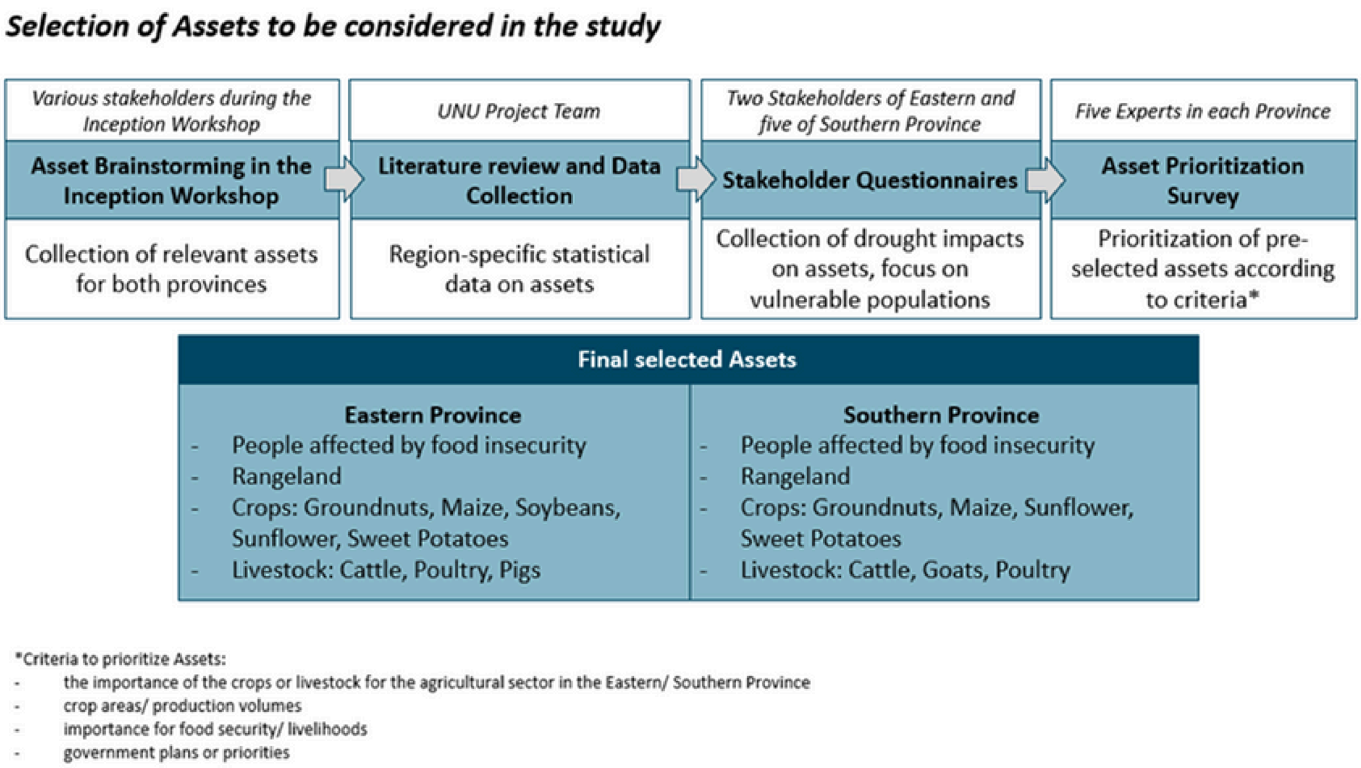

Figure 32: Methodology to select assets for the analysis.

Initial Asset Identification

- Stakeholder suggestions during workshop
- Literature + dataset review

During the Inception Workshop stakeholders provided suggestions for the scope of the analysis, including suggestions for agriculture-related assets. Stakeholders reported that Zambia had experienced recurring droughts with devastating consequences for the agricultural sector and rural livelihoods. Notable events occurred in the agricultural seasons of 1981-1982, 1991-1992, 1994-1995, 2002-2003, 2011-2012, 2018-2019, and most recently in 2023-2024. These events have consistently resulted in widespread crop failures and economic consequences. As some stakeholders indicate, drought disproportionately affects rural populations, particularly those reliant on subsistence agriculture for food and income. To reflect these impacts in the exposure and vulnerability analysis of the study, the following assets were suggested by the stakeholders of the Eastern Province: Crops: Maize, groundnuts, cotton, sunflower, soybeans, cowpeas; Livestock: cattle, pigs, goats, poultry, fisheries; Youth; Grassland/grazing land; Wildlife. To reflect these impacts in the exposure and vulnerability analysis of the study, the following assets were suggested by the stakeholders of the Southern Province at the inception workshop: Crops: Maize, groundnuts, cotton, sunflower, soybeans, cowpeas, sorghum; Livestock: goats, cattle, pigs, poultry, fisheries; Youth; Grassland/grazing land; Water bodies, groundwater.

Asset Prioritization & Validation

- Ranking of crop and livestock importance
- Asset Prioritization Survey
- Final selection of assets per province

Following the workshop, stakeholders from the Eastern Province's Ministry of Fisheries and Livestock were consulted via questionnaires to rank the most important crop and livestock types in the Eastern Province. The Ranking was done according to the importance of crops or livestock to the agricultural sector in the Eastern Province, crop areas/ production volumes, their importance for food security/ livelihoods, and government plans or priorities. The average ranking of the top four crops, according to their importance for the Eastern Region, from 1 (least important) to 10 (most important), is: Maize (10/10), Soybeans (8.8/10), Groundnuts (7.6/10), and Sunflower (7.6/10). The ranking of the livestock types, from 1 (least important) to 6 (most important), suggested that Cattle (6/6), Poultry (4.6/6), and Pigs (4/6) were of high importance. In the Southern Province, agricultural and livestock experts were consulted to rank the most important crop and livestock types, according to the same criteria. The top four crops, ranked from 1 (least important) to 10 (most important for the Southern Region), are: Maize (10/10), Groundnuts (8.6/10), Sunflower (7.7/10), and Sweet Potatoes (7.1/10). The ranking of the livestock types from 1 (least important) to 6 (most important) suggested the high importance of Cattle (6/6), Goats (5/6), and Poultry (3.6/6).

Following final consultations with regional experts, the following assets were included in the assessment of drought risk and adaptation roadmaps for the agricultural sector in the Southern and Eastern Provinces. Due to data gaps in assessing rangelands and poultry, as well as their corresponding drought impacts, rangelands have been excluded from the scope of the study as an asset. The final assets for the Eastern Province include People affected by food insecurity, as well as crops such as groundnuts, Maize, Soybeans, Sunflowers, and Sweet Potatoes, along with livestock, including cattle and pigs. For the Southern Province, the final assets proposed are: People affected by food insecurity, crops, namely Groundnuts, Maize, Sunflower, and Sweet Potatoes, and livestock (in the form of Cattle and Goats).

Asset Localization & Valuation

- Mapping of livestock using global + provincial datasets
- Mapping of crop distribution
- Assigning economic and non-economic values to assets
- Identifying food-insecure populations (IPC Phases 3–5)

Following the definition of assets, they all need to be located and valued. The valuation can be based on both economic and non-economic values, such as the number of people, the number of livestock heads, or crop production volumes. In this study, both economic and non-economic valuations are included for all assets, except for people, for which no economic valuation can be undertaken.

Livestock distribution was initially mapped using a global dataset, which provides high spatial resolution at approximately 10 km pixels, offering a much more detailed picture than national statistical summaries. To ensure accuracy and local relevance, this global layer was validated against official provincial livestock figures obtained from the Ministry of Livestock and Fisheries for both regions, allowing livestock numbers to be calculated and adjusted at the district level. This comparison between global and local data was crucial for enhancing the reliability of the exposure modelling.

For livestock valuation, market prices were established using multiple local sources (Table 7). In the Eastern Province, four-year average market prices (2020–2024) were compiled with support from the provincial agribusiness and marketing departments. Together, these steps ensured that livestock exposure and valuation reflected both high-resolution data and authentic local market realities.

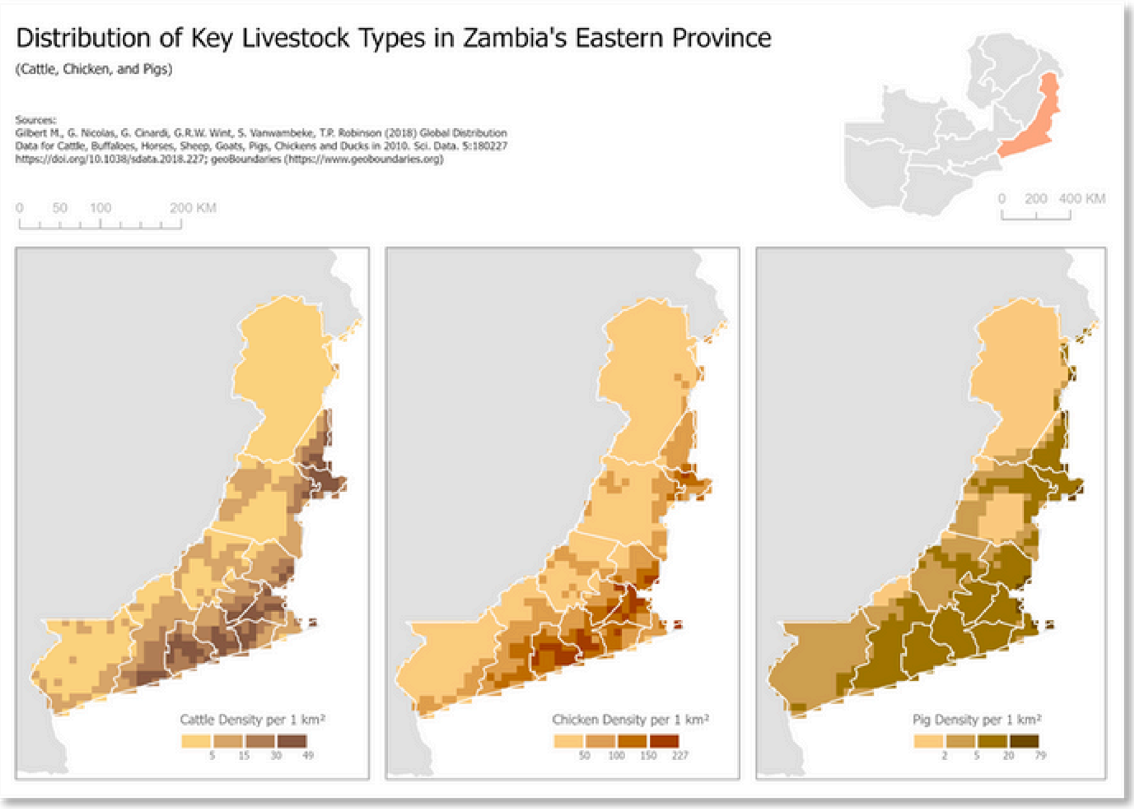

Figure 33: Distribution of key livestock types

Table 7: Average market price of key livestock types

	Cattle	Chicken	Pigs
Average market price (ZMW)	6000	100	900

Crop exposure was first mapped using a global dataset that provides broad spatial information on overall cropland density distribution (Pérez-Hoyos 2018). Building on this layer, locally provided datasets from provincial agricultural offices, including the crop forecast surveys of past years, were used to generate detailed, crop-specific distribution maps. These maps were produced by combining four years of crop forecast survey data and calculating district-level averages for each major crop, which were then overlaid onto the global crop density layer. The result is a new and highly refined product that represents local cropping patterns with unprecedented spatial accuracy. All processed datasets can be shared upon request.

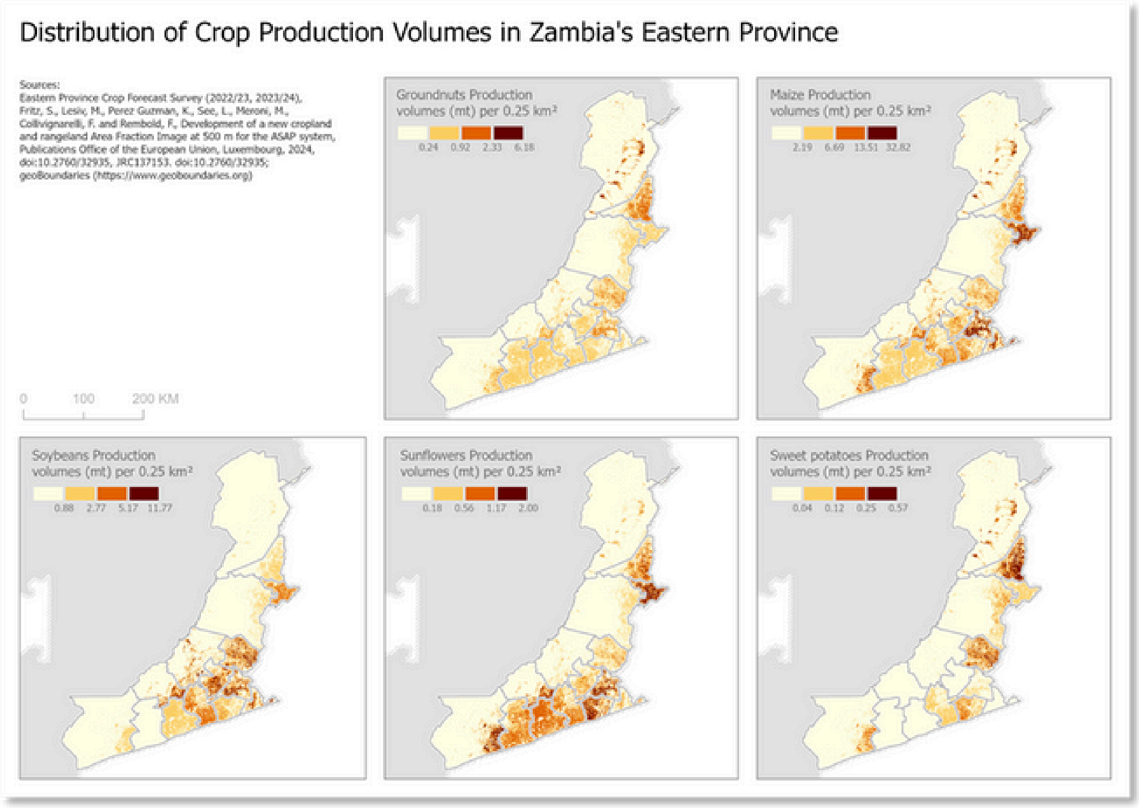

Figure 34: Distribution of key crop types

Table 8: Average market price of key crop types

	Maize	Groundnuts	Soybeans	Sunflower	Sweet potatoes
Average market price 2021 – 2024 (ZMW/ kg)	6	19	7	5	7

The map shows the location and density of the population using Kontur's (Kontur 2022) high-resolution global population dataset (400 m hexagons). This level of detail makes major urban centers, such as Choma in Eastern Province, clearly visible.

To assess the damages of drought on populations as exposed assets, we focus on food insecurity as a metric to assess drought impacts. According to the latest IPC figures from July 2024, very high levels of food insecurity are concentrated in the southern regions, particularly south of the Eastern Province. The IPC uses five food insecurity phases; phases 3–5 indicate high to very high acute food insecurity. The map displays the percentage of the population falling into phases 3–5. This information supports the calibration of our model to project how drought may affect future food insecurity. The IPC was also recommended as a key data source during the inception workshop.

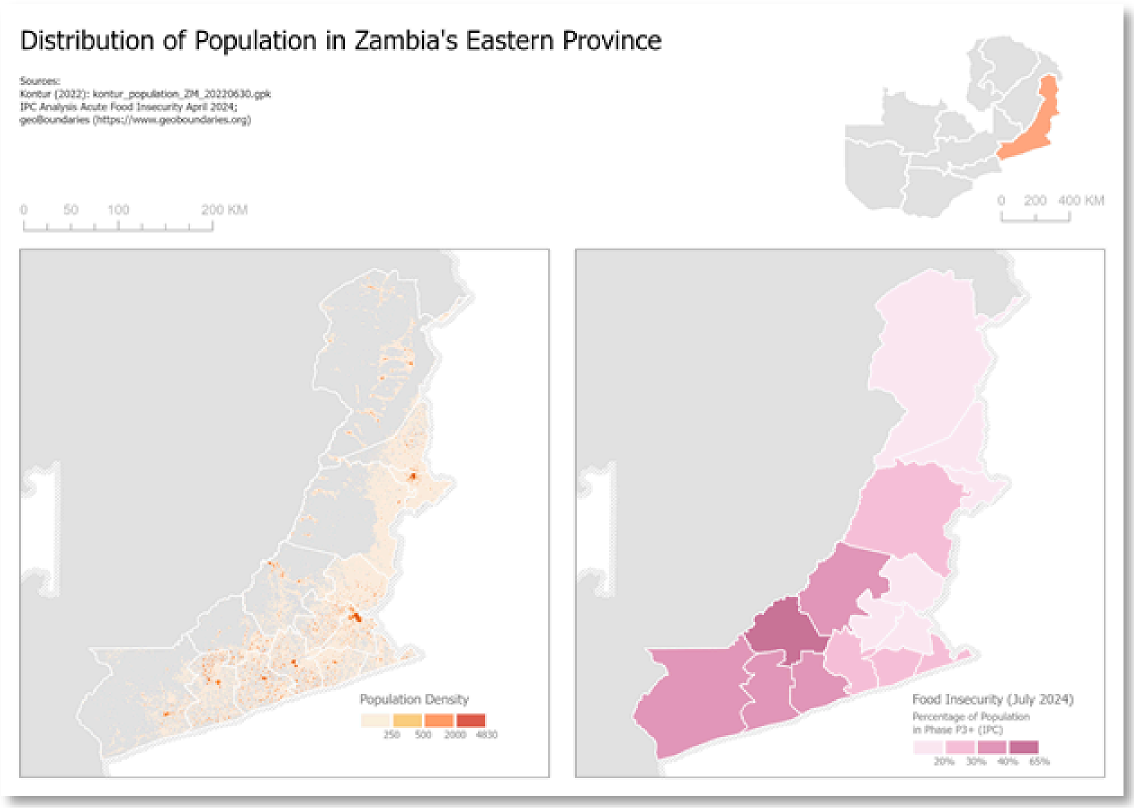

Figure 35: Distribution of population and food security levels

All the data has been validated in a webinar with stakeholders from both provinces.

III. DROUGHT HAZARD MODELLING

- Incorporate climate projections, return periods, and drought scenarios

Drought Model

Drought conditions were modeled using the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010), a widely used metric that accounts for the combined effects of precipitation and temperature on drought severity. The SPEI is derived by applying a log-logistic probability transformation to aggregated water balance anomalies (precipitation minus potential evapotranspiration). Here, we use SPEI_6, which represents water balance anomalies over a 6-month period, to capture seasonal drought trends.

Daily bias corrected precipitation and temperature data (minimum and maximum) were obtained from the Microsoft Planetary Computer (Microsoft Open Source et al. 2022). The source of the meteorological projections was Climate Impact Lab Global Downscaled Projections for Climate Impacts Research (CIL-GDPCIR) (Gergel et al. 2023) at a resolution of 0.22° (~25km), incorporating CMIP6 climate projections (Li 2019) for SSP-245 and SSP-585 climate scenarios. To account for the uncertainty associated with the climate projections, 12 model members ensemble was considered for analyzing drought risks in different hazard scenarios. Based on these 12 model member drought hazards, three representative drought scenarios were extracted, namely Dry Scenario (extreme drought future), Mean Scenario, and Wet Scenario (wettest future). Potential evapotranspiration was calculated using the Hargreaves and Samani (1985) method. The SPEI was computed using the Xclim package (Bourgault et al. 2023). Drought intensity and frequency were analyzed for return periods of 10, 25, 50, and 100 years.

Growth Parameters

Growth parameters in the model are designed to reflect Zambia-specific development pathways. Economic risk projections incorporate a country-specific GDP growth scenario for Zambia sourced from the (The Economist Intelligence Unit). Non-economic risks are modelled using asset-specific growth rates, based on historical crop production and livestock growth trends derived from FAOSTAT data, while population exposure is projected using Zambia's population growth estimates from United Nations, Department of Economic and Social Affairs, Population Division (2025). This is in line with projections that suggest continued growth in livestock production and trade in Sub-Saharan Africa through 2050, although this growth is likely to be intermittently disrupted by disease outbreaks and increasingly severe climate shocks (Global Centre on Adaptation 2022).

IV. RISK AND VULNERABILITY ASSESSMENT

Damage Functions

- Compile provincial data
- Derive drought-specific damage functions for Crops, Livestock, People (food insecurity)

For the risk and vulnerability assessment, local data have been compiled, including Agriculture Status Reports, Vulnerability and Needs Assessment Reports, Livestock Survey Reports, and Crop Forecast Surveys. These and other data were collected to identify damage functions of the assets. The damage functions indicate the degree of damage for each drought intensity and are used in CLIMADA to calculate future monetary and non-monetary risks associated with climate change for the studied assets.

Damage functions are highly context-specific and require careful calibration. The resulting damage functions are as follows. They can be used as guidance and a starting point for similar analyses, but should be adjusted for other projects/ research.

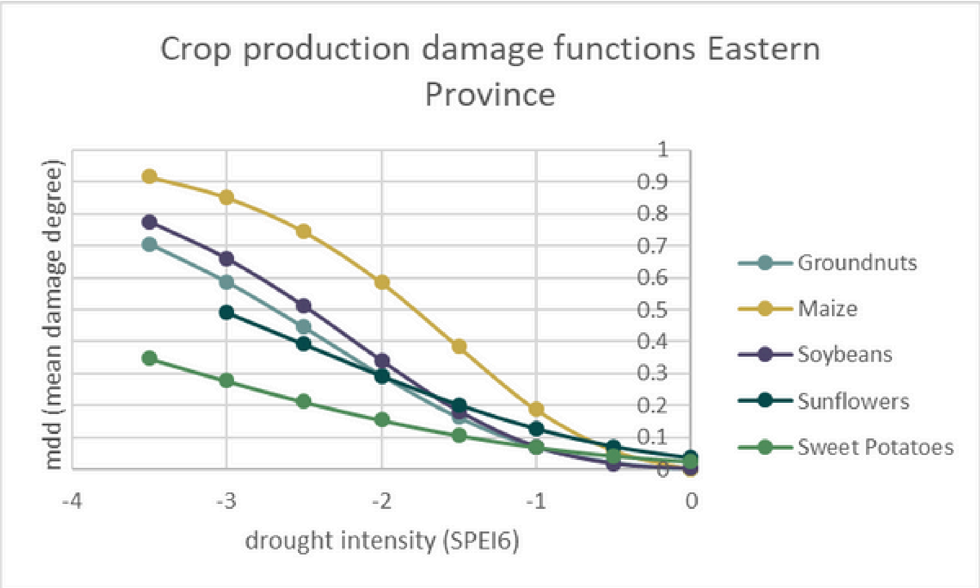

Figure 36: Crop production damage functions, Eastern Province

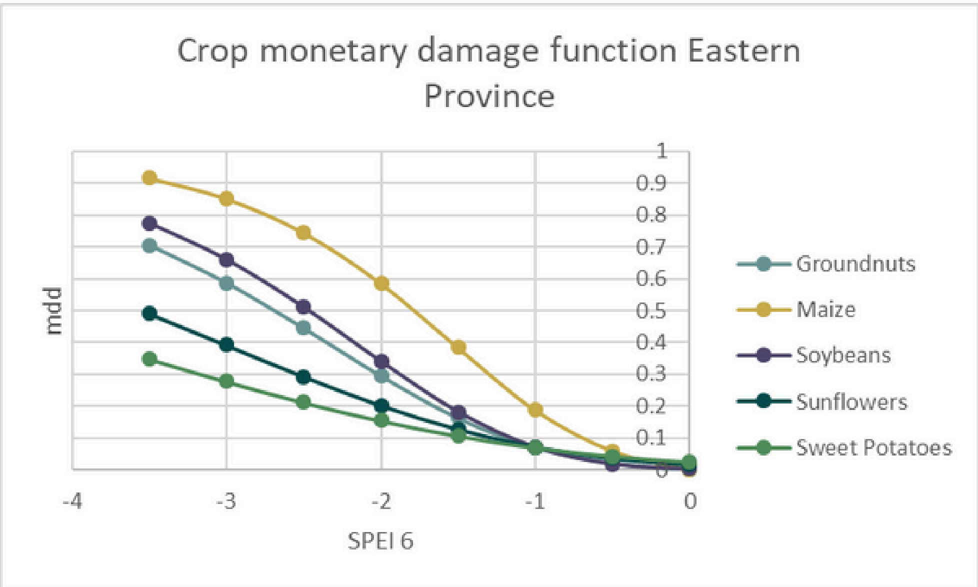

Figure 37: Crop monetary damage functions Eastern Province

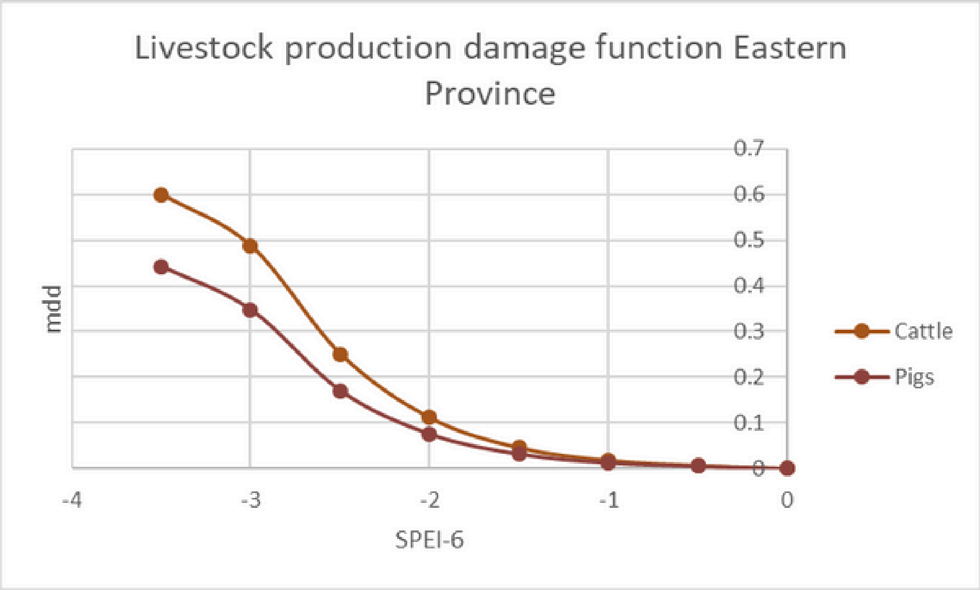

Figure 38: Livestock production damage functions Eastern Province

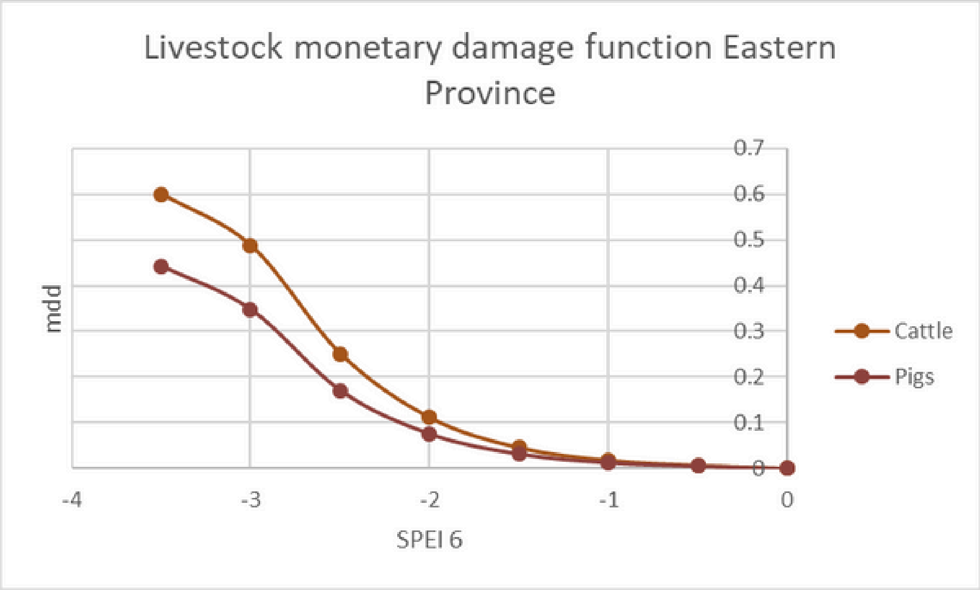

Figure 39: Livestock monetary damage functions Eastern Province

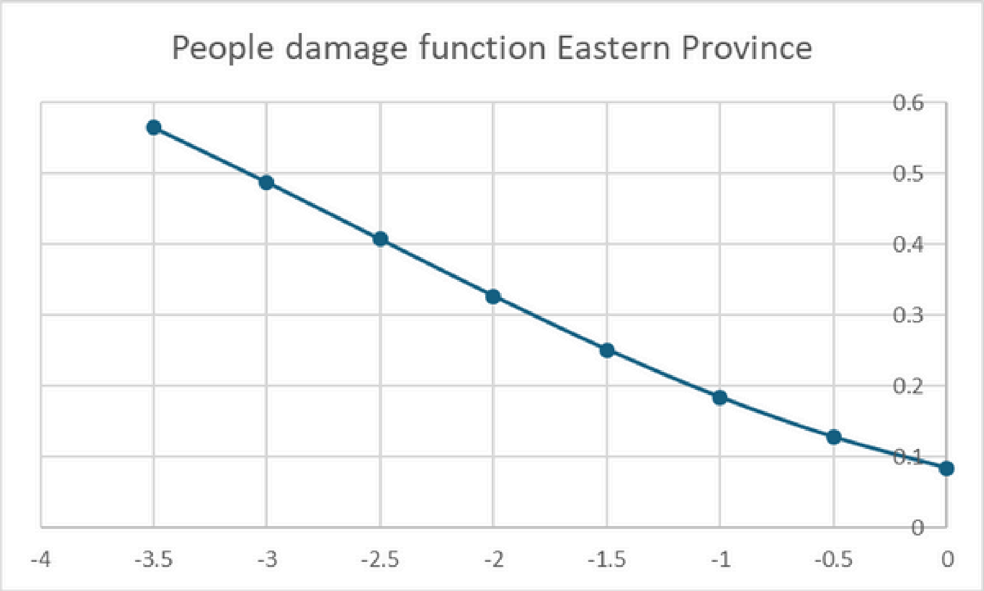

Figure 40: People damage functions, Eastern Province

Calculate Present & Future Risk

- Combine hazard × exposure × impact functions
- Estimate economic and non-economic losses
- Identify drought hotspots

The current average annual risk for the monetary and non-monetary asset categories was calculated using the CLIMADA model. For this, the outcomes of the hazard model, the exposed asset layers, and the impact functions were combined to calculate expected annual impacts. The economic losses are calculated as the expected annual probabilistic losses, which are weighted by the return period frequencies. The calculation of drought hotspots is done based on the hazard hotspot index. This index is calculated using both intensity and frequency dimensions. A combination of Pixels with a hotspot index value greater than or equal to the 80th quantile for hazard and high exposure values (> 70% quantile) has been selected to target high drought impact and high-value pixels. This approach, considering the limited budget scope, served to identify targeted intervention areas in high-risk locations for both domestic and international investments.

V. ADAPTATION ASSESSMENT

From the Long List of Adaptation Measures to Shortlisting

- Brainstorming in workshops from ongoing projects
- Definition of criteria
- Measure shortlisting questionnaires by rating each measure on all criteria

Together with key stakeholders, we held a webinar to scope the adaptation measures that are prominent in Zambia in both regions in the agricultural sector. The discussion centered on various larger projects aimed at enhancing the climate resilience of smallholder and rural populations, as well as the activities implemented within these projects. This was followed by a discussion on the relevant criteria for subsequently ranking these adaptation measures to narrow the list from a long list to a short list of adaptation measures considered for CLIMADA modelling based on the relevant criteria. The suggested criteria have been validated, and the list has been extended with participants' input.

The criteria are listed below:

- Effectiveness: The extent to which a measure reduces drought intensity and strengthens resilience to drought impacts.
- Costs: The measure's affordability, including low investment and maintenance costs, and overall cost-efficiency.
- Co-benefits: The additional positive impacts of the measure, such as contributing to the SDGs, climate change mitigation, and protection from other hazards.
- Social: The degree to which the measure is socially inclusive, gender-responsive, and culturally appropriate.
- Ease of Implementation: How easily the measure can be scaled and implemented with minimal institutional support.
- No harm: The extent to which the measure avoids maladaptation and remains beneficial under different future scenarios (no-regret).
- Coherence with Policies and Plans: The alignment of the measure with national and subnational strategies.
- Green or Grey Measure: The classification of the measure as a nature-based (green) or infrastructural (grey) solution.

The short list of criteria has been identified per adaptation pathway using online questionnaires on Question Pro, where participants rated the measures for all criteria. The long list of measures, as in Figure 41 was then rated on a scale from 1 (low), 2 (medium), to 3 (high) for each measure and each criterion. The results have been summarized per province, with 6 respondents for Southern and 9 respondents for the Eastern region.

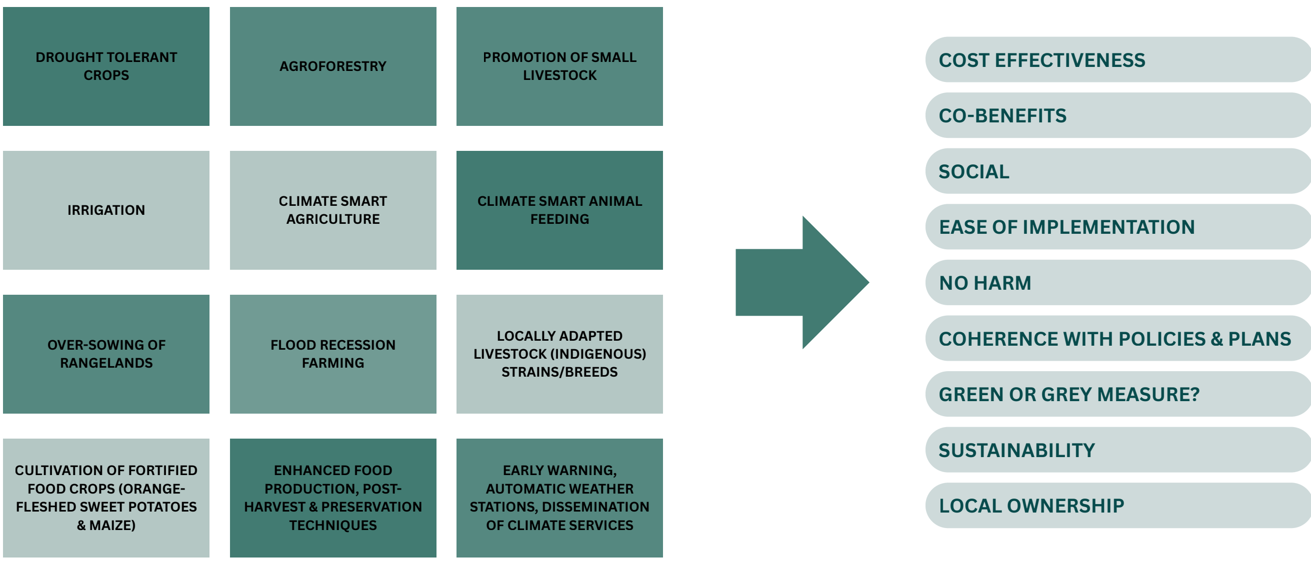

Figure 41: Long list of measures (left) and criteria (right)

Pathway Development

- Allocating measures to pathways based on ranking in the criteria
- Final selection of top 3 preferred pathways

During the Webinar, participants discussed possible Pathway ideas for their regions and identified the relevant criteria for the Pathways based on the list above. The results are included below in Figure 42 and Figure 43:

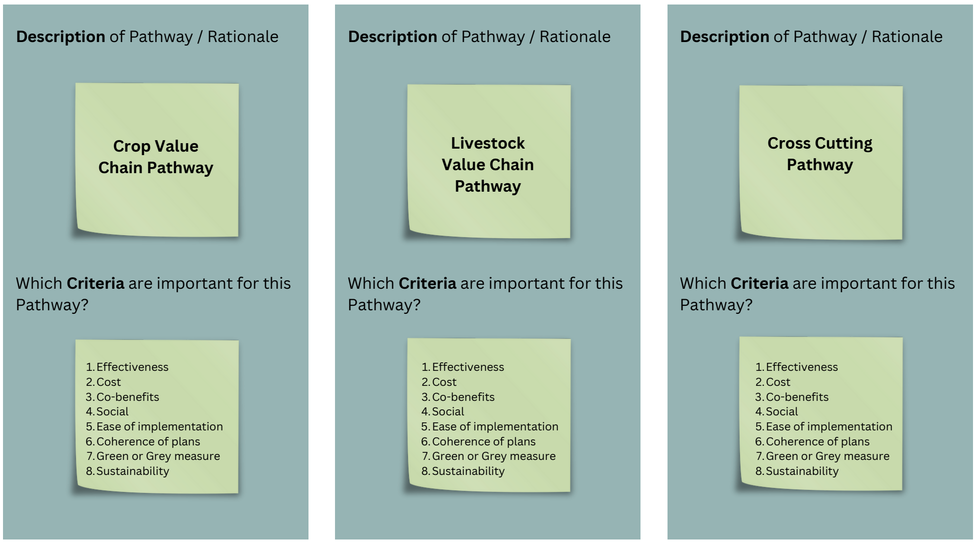

Figure 42: Pathway names and criteria suggestions in the Webinar for the Eastern Province

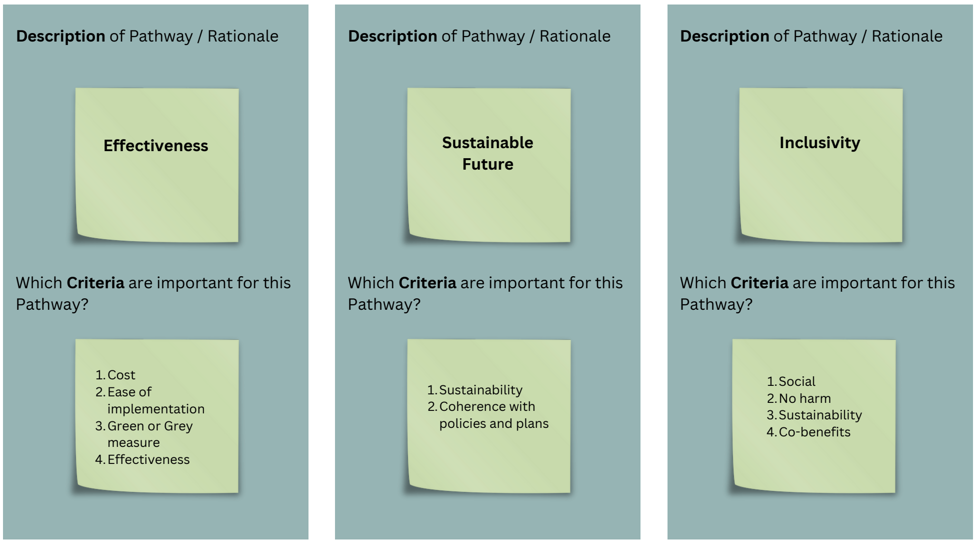

Figure 43: Pathway names and criteria suggestions in the Webinar for the Southern Province

As a next step, the measures have been assigned to the adaptation pathways based on their ranking according to the criteria.

During the workshop, participants have already defined ideas for Pathways and related criteria. Based on follow-up discussions with regional experts, we added two additional possible Pathways to the list of options: Resilient Livestock and Improving Food Security. A total of five possible pathways has been identified, including the relevant criteria, a rationale, and the province-specific measures that have ranked best on the respective combination of criteria per pathway. This long list of options is presented below in Table 9:

Table 9: Options of Adaptation Pathways and Measures.

Pathway	Effectiveness	Green Sustainable Future	Inclusivity	Resilient Livestock	Improving Food Security
Criteria	Cost, Ease of Implementation, Effectiveness	Sustainability, Green Measures, Coherence with Policies and Plans	Social, No harm, Co-benefits	Livestock (Ease of Implementation, Coherence with Policies and Plans, Green measure)	Food Security (Co-benefits, Social)
Rationale	Focuses on delivering high-impact results at low cost through easily implementable solutions that directly reduce drought impacts.	Prioritizes long-term, nature-based solutions that align with national strategies.	Promotes socially inclusive measures that avoid harm and generate wider development and environmental co-benefits.	Focus on sustainable livestock development and resilient livestock and fodder value chains	Promotes measures that directly aim to reduce food security during droughts
Measures (Eastern)	· Enhanced food production, post-harvest, and preservation techniques · Drought-tolerant crops · Locally adapted livestock (indigenous) strains/breed · Promotion of small livestock · Climate Smart Agriculture	· Drought-tolerant crops · Climate Smart Agriculture · Agroforestry · Promotion of small livestock · Climate Smart Animal Feeding	· Enhanced food production, post-harvest, and preservation techniques · Locally adapted livestock (indigenous) strains/breed · Climate Smart Agriculture · Agroforestry · Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)	· Locally adapted livestock (indigenous) strains/breed · Promotion of small livestock · Climate Smart Animal Feeding · Over-sowing of rangelands	· Enhanced food production, post-harvest, and preservation techniques · Early warning, automatic weather stations, dissemination of climate services · Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)
Measures (Southern)	· Drought-tolerant crops · Locally adapted livestock (indigenous) strains/breed · Promotion of small livestock · Agroforestry · Climate Smart Agriculture	· Agroforestry · Climate Smart Agriculture · Drought-tolerant crops · Promotion of small livestock · Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)	· Climate Smart Agriculture · Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize) · Enhance food production, post-harvest, and preservation techniques · Locally adapted livestock (indigenous) strains/breed · Early warning, automatic weather stations, dissemination of climate services	· Locally adapted livestock (indigenous) strains/breed · Promotion of small livestock · Climate Smart Animal Feeding · Over-sowing of rangelands	· Enhanced food production, post-harvest, and preservation techniques · Early warning, automatic weather stations, dissemination of climate services · Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)

To identify priority adaptation pathways and corresponding measures for the two provinces, a second questionnaire has been distributed to experts. A total of 17 responses have been collected, ten from Eastern and seven from Southern Province. Each Participant could rank their top-three choices of the Adaptation Pathways.

The results showed the three preferred Pathways, namely Effectiveness, Green Sustainable Future, and Improving Food Security. The top three measures ranking best on the relevant criteria describing these pathways were included. The final result is shown in Table 10.

Table 10: Final Selection of Pathways and Adaptation Measures.

Pathway	Effectiveness	Green Sustainable Future	Improving Food Security
Criteria	Cost, Ease of Implementation, Effectiveness	Sustainability, Green Measures, Coherence with Policies and Plans	Food Security (Co-benefits, Social)
Rationale	Focuses on delivering high-impact results at low cost through easily implementable solutions that directly reduce drought impacts.	Prioritizes long-term, nature-based solutions that align with national strategies.	Promotes measures that directly aim to reduce food security during droughts
Measures (Eastern)	•Drought-tolerant crops •Locally adapted livestock •Enhanced food production, post-harvest, and preservation techniques	•Drought-tolerant crops •Climate Smart Agriculture •Agroforestry	•Enhanced food production, post-harvest, and preservation techniques •Early warning, automatic weather stations, and dissemination of climate services •Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)
Measures (Southern)	•Drought-tolerant crops •Locally adapted livestock (indigenous) strains/breed •Promotion of small livestock	•Agroforestry •Climate Smart Agriculture • Drought-tolerant crops	•Enhanced food production, post-harvest, and preservation techniques •Early warning, automatic weather stations, and dissemination of climate services •Cultivation of fortified food crops (orange-fleshed sweet potatoes and maize)

Impact Ranking and Costing of Measures

- Stakeholders estimate each measure's impact on reducing drought damages of the assets
- Collection and validation of implementation and maintenance costs

As a subsequent step, and crucial for modelling, the impacts of the adaptation measures on reducing drought vulnerability of the assets they target needs to be evaluated. Participants were asked in the questionnaire, to complete a ranking of the measures' impacts on the assets, estimating for each measure, e.g., Agroforestry, whether it has a high, medium, or low impact on the respective assets, e.g., maize. The results of this impact ranking can be accessed in Table 11, Table 12, and Table 13.

Table 11: Impact ranking of measures on people's food security

	Food Security			
	no/ low impact	medium impact	high impact	N/A
Drought-tolerant crops	0.00%	18.18%	81.82%	0.00%
Agroforestry	0.00%	36.36%	54.55%	9.09%
Promotion of small livestock	0.00%	18.18%	81.82%	0.00%
Irrigation	0.00%	9.09%	90.91%	0.00%
CSA	0.00%	18.18%	81.82%	0.00%
Climate Smart Animal Feeding	0.00%	36.36%	63.64%	0.00%
Locally adapted livestock	0.00%	18.18%	72.73%	9.09%
Cultivation of fortified food crops	0.00%	36.36%	54.55%	9.09%
Enhanced food production, post-harvest, and preservation techniques	0.00%	9.09%	90.91%	0.00%
Early warning, automatic weather stations, and dissemination of climate services	0.00%	36.36%	63.64%	0.00%

Table 12: Impact ranking of measures on livestock

	Cattle				Pigs				Goats				Chickens			
	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A
Drought-tolerant crops	0.00%	63.64%	27.27%	9.09%	18.18%	36.36%	27.27%	18.18%	18.18%	9.09%	54.55%	18.18%	0.00%	27.27%	54.55%	18.18%
Agroforestry	0.00%	54.55%	36.36%	9.09%	27.27%	36.36%	18.18%	18.18%	0.00%	36.36%	45.45%	18.18%	9.09%	54.55%	9.09%	27.27%
Promotion of small livestock	18.18%	36.36%	27.27%	18.18%	9.09%	63.64%	27.27%	0.00%	0.00%	27.27%	72.73%	0.00%	9.09%	18.18%	72.73%	0.00%
Irrigation	9.09%	45.45%	36.36%	9.09%	27.27%	36.36%	18.18%	18.18%	36.36%	36.36%	18.18%	9.09%	18.18%	54.55%	18.18%	9.09%
CSA	9.09%	63.64%	18.18%	9.09%	27.27%	45.45%	18.18%	9.09%	18.18%	36.36%	36.36%	9.09%	9.09%	54.55%	27.27%	9.09%
Climate Smart Animal Feeding	0.00%	27.27%	72.73%	0.00%	9.09%	45.45%	45.45%	0.00%	0.00%	36.36%	63.64%	0.00%	0.00%	45.45%	54.55%	0.00%
Locally adapted livestock	9.09%	18.18%	72.73%	0.00%	18.18%	27.27%	54.55%	0.00%	0.00%	18.18%	81.82%	0.00%	0.00%	45.45%	54.55%	0.00%
Cultivation of fortified food crops	9.09%	63.64%	0.00%	27.27%	9.09%	63.64%	0.00%	27.27%	18.18%	45.45%	9.09%	27.27%	9.09%	54.55%	9.09%	27.27%
Enhanced food production, post-harvest, and preservation techniques	9.09%	45.45%	18.18%	27.27%	18.18%	36.36%	18.18%	27.27%	27.27%	36.36%	18.18%	18.18%	18.18%	45.45%	18.18%	18.18%
Early warning, automatic weather stations, and dissemination of climate services	18.18%	36.36%	45.45%	0.00%	27.27%	27.27%	45.45%	0.00%	27.27%	27.27%	45.45%	0.00%	27.27%	27.27%	45.45%	0.00%

Table 13: Impact ranking of measures on crops

	Maize				Groundnuts				Soybeans				Sunflowers				Sweet Potatoes			
	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A	no/ low impact	medium impact	high impact	N/A
Drought-tolerant crops	0.00%	45.45%	54.55%	0.00%	0.00%	45.45%	45.45%	9.09%	0.00%	36.36%	54.55%	9.09%	18.18%	18.18%	63.64%	0.00%	0.00%	36.36%	63.64%	0.00%
Agroforestry	0.00%	45.45%	45.45%	9.09%	9.09%	54.55%	18.18%	18.18%	9.09%	54.55%	27.27%	9.09%	9.09%	63.64%	18.18%	9.09%	27.27%	45.45%	9.09%	18.18%
Promotion of small livestock	9.09%	36.36%	36.36%	18.18%	9.09%	27.27%	27.27%	36.36%	9.09%	45.45%	18.18%	27.27%	18.18%	36.36%	18.18%	27.27%	27.27%	45.45%	9.09%	18.18%
Irrigation	0.00%	9.09%	90.91%	0.00%	9.09%	27.27%	45.45%	18.18%	9.09%	36.36%	36.36%	18.18%	9.09%	27.27%	45.45%	18.18%	0.00%	54.55%	45.45%	0.00%
CSA	0.00%	9.09%	90.91%	0.00%	0.00%	9.09%	90.91%	0.00%	0.00%	18.18%	81.82%	0.00%	0.00%	9.09%	90.91%	0.00%	0.00%	45.45%	54.55%	0.00%
Climate Smart Animal Feeding	36.36%	36.36%	9.09%	18.18%	36.36%	27.27%	9.09%	27.27%	36.36%	36.36%	0.00%	27.27%	45.45%	27.27%	9.09%	18.18%	45.45%	27.27%	0.00%	27.27%
Locally adapted livestock	9.09%	27.27%	27.27%	36.36%	0.00%	27.27%	18.18%	54.55%	9.09%	27.27%	9.09%	54.55%	9.09%	36.36%	18.18%	36.36%	9.09%	36.36%	9.09%	45.45%
Cultivation of fortified food crops	9.09%	36.36%	45.45%	9.09%	18.18%	36.36%	9.09%	36.36%	27.27%	36.36%	0.00%	36.36%	27.27%	36.36%	0.00%	36.36%	18.18%	27.27%	54.55%	0.00%
Enhanced food production, post-harvest, and preservation techniques	9.09%	36.36%	54.55%	0.00%	9.09%	36.36%	54.55%	0.00%	9.09%	36.36%	54.55%	0.00%	9.09%	36.36%	54.55%	0.00%	9.09%	36.36%	54.55%	0.00%
Early warning, automatic weather stations, and dissemination of climate services	0.00%	36.36%	63.64%	0.00%	0.00%	36.36%	63.64%	0.00%	0.00%	36.36%	63.64%	0.00%	0.00%	36.36%	63.64%	0.00%	9.09%	45.45%	45.45%	0.00%

Another important parameter in the adaptation assessment in CLIMADA is the cost of the measures, i.e., the implementation costs for the setup and the annual maintenance costs. Participants have been asked to provide costs for the measures and the average costs have been compiled and used for further CLIMADA modelling. The costs can be accessed in Table 14.

Table 14: Overview of costs for adaptation measures.

	Implementation costs (ZMW)	**Maintenance costs/ year (ZMW)**	**Unit/ scale**
Drought-tolerant crops	12,250	3,936	Ha
Agroforestry	9,756	3,180	Ha
Promotion of small livestock	1,942	548	Head
Climate Smart Agriculture (CSA)	16,006	3,594	Ha
Locally adapted livestock	4,524	1,872	Head
Cultivation of fortified food crops	12,241	2,825	Ha
Post-harvest and preservation techniques	5,488	1,821	Ha
Early warning, automatic weather stations, dissemination of climate services	87,255	7,583	Weather Station

For the validation of the questionnaires' results, we discussed all rankings with provincial experts in agriculture and livestock to exclude misleading results or clarify any details. Further consultations took place to discuss other parameters for CLIMADA, e.g., the implementation timeline. This included the co-creation of a handout summarizing the adaptation measures and their implementation.

Table 15: Overview of Adaptation Measures

Drought-tolerant Crops	
Implementation Costs (ZMW)	12,300
Maintenance Costs (ZMW)	4,000
Time needed to prepare measure (Time from start of implementation until the measure is effective)	This will include the period for all the agricultural activities from land preparation to marketing that is September to July(9 months).
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also	All Districts in the Provinces
Target benefits of the measure? Improved and increased crop production and productivity that ultimately result into increased household income, food and nutrition security thereby improving livelihoods	
Description of Implementation: Using the lead and follower farmer model, a few selected farmers can be supplied with start-up input packs with a focus and emphasis on capacity building through trainings and demonstrations	
Agroforestry	
Implementation Costs (ZMW)	9,800
Maintenance Costs (ZMW)	3,200
Time needed to prepare measure (Time from start of implementation until the measure is effective)	1 Year
Life Span with maintenance (if maintenance)	10 Years
Suitable locations for implementation (e.g., specific districts, also	All the District in the Provinces
Target benefits of the measure? Long term benefits include: improved soil structure and fertility resulting in improved crop production and productivity leading increased household income and enhanced food and nutritional security	
Description of Implementation Establishment of seedling and seed banks Establishment of demonstration sites and field schools Recruitment of lead and follower farmers	

Climate-Smart Agriculture (Crop Rotation, Minimum tillage, Retention of crop residues, Organic manure)	
Implementation Costs (ZMW)	16,000
Maintenance Costs (ZMW)	3,600
Time needed to prepare measure (Time from start of implementation until the measure is effective)	This will include the period for all the agricultural activities from land preparation to marketing that is September to July(9 months); On a three (3) year rotational basis
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also all are possible)	All the Districts in the Provinces
Target benefits of the measure? Improved and increased crop production and productivity that ultimately result into increased household income, food and nutrition security thereby improving livelihoods Improved soil structure and fertility with ability to maintain soil moisture	
Description of Implementation: Using the lead and follower farmer model, a few selected farmers can be supplied with start-up input packs with a focus and emphasis on capacity building through trainings and demonstrations	
Locally adapted livestock (indigenous) strains/breed	
Implementation Costs (ZMW)	4,500
Maintenance Costs (ZMW)	1,900
Time needed to prepare measure (Time from start of implementation until the measure is effective)	1 Year
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also all are possible)	All Districts in the Provinces Emphasis on the Valley areas (because most impacted by changing climate/ high temperatures)
Target benefits of the measure? Improved and increased availability of the indigenous breed - Smaller in size, require less water (but produce less meat/milk) - More tolerant regarding diseases - Applies mainly to cattle, also goats à more adaptable to longer droughts - Lower costs of procuring compared to other breeds (4-5 times) - Crosses between indigenous and improved breeds - General trend is supporting improved breeds (bigger size, higher productivity for farmers) - In the valley areas the indigenous breeds are more common - Consumer prefers the indigenous (better taste)	

Description of Implementation: Using the pass-on model, a few farmers can be supplied with indigenous breeds to raise the livestock, and after a cycle, other farmers can also be given either the offspring or the parent stock.	
Cultivation of fortified food crops (orange-fleshed sweet potatoes and vit A-maize)	
Implementation Costs (ZMW)	12,200
Maintenance Costs (ZMW)	2,800
Time needed to prepare measure (Time from start of implementation until the measure is effective)	This will include the period for all the agricultural activities from land preparation to marketing that is September to July (9) months
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also all are possible)	All Districts in the Provinces.
Target benefits of the measure? Improved and enhanced household incomes, food and Nutrition security Goal: improve Vit A intake for better health Focus on nutrition Benefits: improves nutrition security and shorter growing period compared to ordinary maize/ sweet potatoes/ common beans enriched in iron Positive benefits under drought conditions: will provide better food and nutrition security compared to ordinary; part of crop diversification strategy	
Description of Implementation: Using the lead-follower farmer model, a selected few farmers can be supplied with start-up inputs pack with a focus and emphasis on capacity building through trainings and demonstrations	
Promotion of small livestock (production, bulking, processing, and marketing)	
Implementation Costs (ZMW)	
Maintenance Costs (ZMW)	
Time needed to prepare measure (Time from start of implementation until the measure is effective)	
Life Span with maintenance (if maintenance)	
Suitable locations for implementation (e.g., specific districts, also all are possible)	
Target benefits of the measure? This will bring about improved and increased livestock production and productivity that will result into enhanced and increased household income, food and nutrition security thereby improving livelihoods. Easier to sell during droughts than large livestock for families to purchase food. Cattle require more water compared to small livestock. Small livestock is more drought-resilient than crops.	
Description of Implementation: This could include supplying improved livestock breeds and establishment of livestock service centers in some selected veterinary camps in the District.	

Enhanced food production, post-harvest, and preservation techniques	
Implementation Costs (ZMW)	5,500
Maintenance Costs (ZMW)	1,800
Time needed to prepare measure (Time from start of implementation until the measure is effective)	1Year
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also all are possible)	All Districts in the Provinces
Target benefits of the measure? Improved and increased crop production and productivity, as well as reduced post-harvest loss which ultimately results in increased household income, food, and nutrition security, thereby improving livelihoods Secure that the reduced production is stored correctly and ensures food security. Overall importance to maintain and use the food produced to not increase production areas and thereby protect the environment and adapt to climate change. Reduce the greenhouse gas emissions due to post-harvest losses (mitigation). Increasing production and productivity lead to higher household income.	
Description of Implementation: Using the lead and follower farmer model a selected few farmers can be supplied with a start-up inputs pack and post-harvest equipment that may include improved storage facilities, with a focus and emphasis on capacity building through training and demonstrations	
Early warning, automatic weather stations, dissemination of climate services	
Implementation Costs (ZMW)	87,300
Maintenance Costs (ZMW)	7,600
Time needed to prepare measure (Time from start of implementation until the measure is effective)	1 Year
Life Span with maintenance (if maintenance)	3 Years
Suitable locations for implementation (e.g., specific districts, also all are possible)	All Districts in the Provinces
Target benefits of the measure? Improved access to climate information that will result in timely and informed decisions for example when to plant.	
Description of Implementation: Installation and establishment of improved weather stations in all the Districts and dissemination of climate information on the local radio stations in both English and local languages.	

VI. PREPARATION FOR CLIMADA ADAPTATION MODELLING

Upon completion of data collection for the adaptation measures and pathways, the data must be prepared for inclusion in CLIMADA, using so-called entity files. The mandatory information for adaptation-related inputs includes the cost of the measures, inclusive of all related expenses, parameters that depict how the measures act (i.e., hazard-related, impact function, and percentage of exposed assets-related parameters), the regions where the measures would be applied, and the timeline of the measures. For both investment scenarios, the measures would act primarily on the hotspot pixels.

Budget Scenarios

- Domestic funding: USD 1M every 4 years → total USD 6M
- International funding: USD 10M every 4 years → total USD 60M
- Allocation of budgets per measure inside Pathways

We calculated the total investment per adaptation pathway and the corresponding adaptation measures for both domestic investment scenarios and international investment scenarios. Based on the Ministry of Agriculture's annual budget for 2024, the national budget is ZMW 180 billion . Of these, ZMW 13 billion are reserved for Agriculture, of which 80% are allocated to the Farmer Input Support Programme (FISP). Based on these numbers, we calculated that approximately USD 1 million would be available annually to support the implementation of one Pathway per Province. Considering that other programs will also implement and claim national budgets, we assume an allocation of USD 1 million only every 4 years on average. This timeline corresponds to the average lifespan of the considered adaptation measures, as advised by experts, with a 1-year implementation period followed by a 3-year maintenance period. After this period, the measure reaches the end of its lifespan and should be reintroduced and reassessed in the model. Considering the time horizon for assessing these adaptation pathways and their benefits in reducing drought risks in the provinces until 2050, most adaptation measures will be introduced six times, with the exception of agroforestry, which has a longer lifespan of 11 years and will only be introduced twice.

We allocate the same budget to all adaptation measures within a single pathway, irrespective of their lifespan or individual implementation costs, and assume reinvestment of USD 1 million every 4 years to sustain positive adaptation benefits until 2050. This translates to USD 6 million, which will be needed under the domestic funding scenario to fully finance and maintain one Pathway in one Province, equivalent to USD 2 million per adaptation measure.

Following discussions with stakeholders, the benefits of introducing an international budget scenario for all pathways have been explored and considered a useful basis for applying for climate funding. The intended quadrennial investments will be 10 times the domestic expenses, thus USD 10 million every four years.

Scaling of Measures

Based on the implementation and maintenance costs of the adaptation measures, we can calculate the total area, tons, and heads for each targeted asset, given a USD 2 million domestic budget (USD 20 million for the international budget). We also consider the different prevalence of the assets, for instance, maize makes up 64% of all crop assets in the Eastern Province, and 64% of the available budget for measures will target the maize asset, if suitable under this adaptation measure. As follows, more hectares of maize will be protected by an agricultural adaptation measure than hectares of sunflower (6% of the considered agricultural production in the Eastern Province). Province-specific multi-year average yields per crop are applied for this purpose.

Scaling of Measures

- Domestic: top 20% drought hotspots + 30% high exposure areas
- International: top 30% drought hotspots + 30% high exposure areas
- Randomize placement within hotspots

The measures are randomly distributed in the model, based on drought hotspots. To model the implementation areas of the adaptation measures, we calculate the drought hotspots for each pixel. For the domestic budget, the high-risk area is defined as the 20% most-at-risk pixels based on the hotspot index and high exposure areas. For the international budget scenario, with a larger budget, we extend the threshold to the 30% most-at-risk areas. These hotspots are combined drought hotspots based on intensities and frequencies, calculated over four different drought return periods for each pixel. The actual location for implementing the measure within these drought risk hotspots needs to be defined in the next step, with a feasibility study. Hence, the calculated benefits represent the average benefits of the measure, regardless of where it is exactly implemented, in these high-drought-risk areas.

The benefits of the adaptation measures are calculated as the averted damages due to their implementation. For example, for locally adapted livestock breeds, the indigenous breeds are more resilient to droughts compared to other breeds. In CLIMADA, the adapted breeds were modeled in the drought hotspot areas compared to the normal animals, and the averted drought impacts due to the adapted breeds are the benefits of the adaptation measure. We assume average growth rates for livestock and crops based on past FAO data to also apply to new and improved varieties, considering also possible multiplier effects and adoption by other farmers. With every new investment, usually every four years, more crops or livestock can be protected, adding to the growing rate of crops and livestock already targeted by the implemented adaptation measures. We consider maintenance costs, including any additional maintenance required during the first implementation period. After the first round of implementation and maintenance (4 years, except for agroforestry, 10 years), we include a sustainability and multiplier parameter. We assume continued practice implemented by farmers themselves, and considering the lead-farmer follower-farmer model, we also assume application by other farmers who are convinced by the resilient practices. We apply a conservative growth rate over the years, simply reflecting the area growth rates of the asset targeted by the measure. This reflects that the asset under the adaptation measure is growing at the same rate as normal asset growth, i.e., Maize under CSA cultivation will grow at the same rate as “normal” maize.

VII. CLIMADA ADAPTATION MODELLING

- Domestic funding: USD 1M every 4 years → total USD 6M
- International funding: USD 10M every 4 years → total USD 60M
- Allocation of budgets per measure inside Pathways

For adaptation modelling, a snapshot-based approach was implemented to validate the performance of open-source tools, such as CLIMADA, in better simulating the real-world effectiveness of adaptation measures over time. Rather than assuming static impacts, this method evaluates measures in cycles (six cycles of four years for all except Agroforestry at two cycles of 11 years), consisting of one year of implementation followed by three years of accrued benefits, including maintenance costs when necessary. The exposure of agricultural assets is modeled dynamically and defined by economic or population growth rates. By aggregating costs and avoided damages at the end of each cycle, the framework delivers transparent and comparable cost–benefit metrics across different timelines. The increasing benefit/cost ratio observed during simulation with each implementation reflects the ability of CLIMADA to capture the dynamics of adaptation in a progressively increasing hazard severity and economic growth scenario. This also allows for realistic integration of the spillover and takeover effects by farmers, where successful agricultural and climate change adaptation practices are adopted and implemented beyond the scope of a project. The snapshot approach was useful for reflecting continuous implementation of adaptation practices over the timeframe of the analysis, respecting budget volumes and related possible scopes of implementation within the domestic or international budget volumes for each cycle. We thus present this approach as a niche to support policy assessment by aligning adaptation evaluation with realistic planning horizons, budget cycles, and staggered implementation.

The adaptation measures exhibit varying rates of effectiveness in mitigating the impacts of drought. This effectiveness is further nuanced by the respective assets they are targeting. CLIMADA calculates the avoided damages of each adaptation measure for every single asset, also considering the effectiveness ranking provided by stakeholders for this purpose. The model is calibrated to demonstrate the effectiveness of the measures in reducing drought-related risks and provides benefit-cost rankings, considering both the implementation and, if necessary, maintenance costs of the adaptation measure. This approach differs from other cost-effectiveness analyses, as its effectiveness is based solely on the measure's ability to reduce drought damages and does not include other co-benefits.

The co-benefits of the measure can be either monetary or non-monetary. Monetary co-benefits directly influence the monetary benefits of the adaptation measure and, with that, the benefit-cost ratio. For crops, monetary co-benefits include income generated through the sale of the produced output, whereas non-monetary co-benefits can include improved ecosystem resilience and biodiversity protection. These monetary and non-monetary benefits have not been included in the benefit-cost ratio calculation for drought adaptation. However, these additional benefits need to be considered when evaluating the benefit-cost ratios, as those below 1, i.e., higher costs than benefits from avoided drought damages, are likely to be cost-effective overall when considering co-benefits through production gains, etc. For livestock, we considered monetary co-benefits due to the sale of meat and milk, based on data from FAOSTAT. The calculated benefits are closer to capturing the overall benefits of the improved livestock, like the drought-resistant breeds, by including both drought adaptation benefits and the general benefits of production sales. The benefits of adaptation measures for people have been approximated by the benefits of crop production. In this sense, the benefits of adaptation measures to reduce drought-induced food insecurity can also be considered a co-benefit of the protected crop productivity from droughts through these measures and the corresponding reduced monetary losses. Though crop production residuals are also used as livestock feed, due to the lack of data, improved livestock resilience due to adaptation measures primarily targeting crop assets, such as Agroforestry, has not been included.

VIII. APPENDIX BIBLIOGRAPHY

Bourgault, Pascal; Huard, David; Smith, Trevor James; Logan, Travis; Aoun, Abel; Lavoie, Juliette et al. (2023): xclim: xarray-based climate data analytics. In JOSS 8 (85), p. 5415. DOI: 10.21105/joss.05415.

Esterhuizen, D. (2024): Zambia Depends on Corn Imports to Maintain Food Security. USAID. Available online at https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Zambia%20Depends%20on%20Corn%20Imports%20to%20Maintain%20Food%20Security_Pretoria_Zambia_ZA2024-0001.pdf.

Gergel, Diana R.; Malevich, Steven B.; McCusker, Kelly E.; Tenezakis, Emile; Delgado, Michael T.; Fish, Meredith A.; Kopp, Robert E. (2023): Global downscaled projections for climate impacts research (GDPCIR): preserving extremes for modelling future climate impacts.

Global Centre on Adaptation (2022): State and Trends in Adaptation. Livestock. Available online at https://gca.org/wp-content/uploads/2023/01/GCA_State-and-Trends-in-Adaptation-2022_Livestock.pdf.

Hargreaves, George H.; Samani, Zohrab A. (1985): Reference Crop Evapotranspiration from Temperature. In Applied Engineering in Agriculture 1 (2), pp. 96–99. DOI: 10.13031/2013.26773.

Li, Lijuan (2019): CAS FGOALS-g3 model output prepared for CMIP6 CMIP. With assistance of Lijuan Li, Yongqiang YU, Li Dong, Jinbo Xie, Yanli Tang.

Microsoft Open Source; Matt McFarland; Rob Emanuele; Dan Morris; Tom Augspurger (2022): microsoft/PlanetaryComputer: October 2022: Zenodo.

Pérez-Hoyos, Ana (2018): Global crop and rangeland masks. European Commission, Joint Research Centre (JRC) [Dataset] PID. Available online at http://data.europa.eu/89h/jrc-10112-10005.

The Economist Intelligence Unit: Real GDP (% change pa). Available online at https://viewpoint.eiu.com/data/results?searchId=c7989395-73c2-4efb-9c3a-24705f015f66, checked on 10/31/2025.

United Nations, Department of Economic and Social Affairs, Population Division (2025): World Population Prospects 2025, Online Edition.

Vicente-Serrano, Sergio M.; Beguería, Santiago; López-Moreno, Juan I. (2010): A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. In Journal of Climate 23 (7), pp. 1696–1718. DOI: 10.1175/2009JCLI2909.1.