Developing Pathways for Sustainable Agricultural Development in Zimbabwe by 2030

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Abstract Agricultural production systems in Zimbabwe are facing high intensity of climate change impacts. Stakeholders require actionable information to direct investments towards a climate resilient future. The Agricultural Model Inter-comparison and Improvement Project, Climate Change Adaptation and Resilience (AgMIP CLARE) uses an integrated multi-modeling approach to support policy-level decision making and priority setting for sustainable development and climate adaptation with the goal of improving farmers' livelihoods, food and nutrition security and gender equity. The Zimbabwe Vision 2030 was used to co-develop, with stakeholders' and experts, plausible future scenarios of the agricultural sector in Zimbabwe. For systems like in Nkayi district, the simulation results illustrate that investing in a sustainable

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future, yields more favourable outcomes than investing in 'high emission' economic growth: pro-active diversification and intensification of small (traditional) grains and legumes and integration with livestock, supported by inclusive, functional value chains and access to information leads to higher returns per unit land on farm. Policies and interventions that promote a switch to more legumes in the farming systems, and make the uptake of productivity enhancing technologies more attractive, achieve greater food and nutrition security and increase social and economic equity, offset the impacts of climate change and improve farmers livelihoods. Importantly, to make effective investments there is need to create incentives for all farmers to invest; under a sustainable future, vulnerability is less and the poorest benefit more. Deciding for one future helps prioritizing what it would take in terms of policies and investments to achieve the vision 2030. Testing technologies and adaptations under different possible futures, integrating socio-economic and agro-ecological dimensions across different scales, simulation experiments helps stakeholders and experts to design and evaluate policies aimed at meeting sustainable development, climate and food security goals.

Keywords Climate change adaptation · AgMIP CLARE · AgMIP representative agricultural pathways · Zimbabwe

Introduction

Climate change amplifies challenges in agriculture, particularly in drylands, where water is already scarce, bio-diversity dwindling, against an ever raising pressure to nourish human populations. Dryland areas in Zimbabwe cover more than two thirds of the country, facing high intensity of climate change impacts (Moyo 2012). Given the levels of risk and uncertainty, there is need for science to serve decision purposes, direct policy investments, on what to put in place towards a climate resilient future (Lipper et al., 2014). Science informed decision making is increasingly becoming important, to improve agricultural systems, in their function to deliver food and nutrition, as changes take place in agriculture, climate and socio-economic conditions, now and in the future (Antle et al. 2015).

The main reason why agricultural development pathways are being created is to shape policy and investment decisions on how Zimbabwe can best achieve sustainable agricultural development and how to achieve the set goals of its vision 2030. Researchers engage with stakeholders and sectoral experts in an iterative process, to bringing in different sources of knowledge that inform the dialogue on major drivers for agricultural production, their interactions and how those might influence the state of the future. Development pathways are based on sound baseline analyses of current policy, institutional and socio-economic conditions and different trajectories representing development goals, policy implementation and challenges. These pathways allow to assess the potential impacts and trade-offs associated with the scenarios which can be used to support decisions, planning and investment. Climate policy plays a key role on the ability of the country to implement adaptation and mitigation strategies conducive of achieving climate goals and international commitments (e.g. Paris agreement). Therefore, climate policy assumptions along the pathways create the different scenarios to assess the changes in the farming systems. This informs actionable climate change adaptation options, tailored to areas with similar bio-physical and socio-economic conditions and accounting for plausible futures that cannot be measured and tested using traditional methods of field experimentation.

Research outputs include:

1. Pathways for agricultural development validated with stakeholders and experts, representing impacts of climate and other socio-economic influences, and how changes in policies are likely to impact on agriculture and the wider food systems.
2. Consolidation of policy packages for sustainable and resilient agri-food systems, costs, feasibility and impacts, supporting desirable transitions based on sound policy analyses and requirements.
3. Actionable information on how pathways can be implemented, as to where to transition from, where to go, based on well aligned priorities and entry points.
4. Analyses of the consequences (impacts) if sustainability goals are different or implementation of sustainable development policies are not fully implemented.

In this chapter, the advancement in creating and implementing development pathways within an integrated modeling approach to inform policy decision processes in Zimbabwe is reported. The chapter draws on a case study within the global Agricultural Modeling Intercomparison and Improvement Project (AgMIP, www.agmip.org).

Addressing systemic challenges to agriculture and climate change adaptation:

Policy and decision makers in the Zimbabwe agriculture sector face daunting task to enable sustainable increases in productivity and nourish a growing and developing population under a changing climate, and growing regional and global challenges (Mbow et al. 2019). To achieve its vision 2030 of being a prosperous and empowered upper middle income society, the agricultural sector must fulfil key goals (Fig. 1a).

Policy decisions must transform agricultural production systems, with more efficient resource utilization, water and input use, improving soil health and rangeland bio-diversity, decreasing green-house gas emissions, facilitating economic growth in a way that it engages women and youth.

Climate change acts as risk multiplier (Moyo and Nangombe 2015). Climate change enhances the urgency of transforming to a more inclusive, competitive and sustainable agricultural system (Rickards and Howden 2012; Kates et al. 2013). Food, nutrition and income challenges are wide spread, affecting the rural and urban poor. Drylands are projected to have most negative impacts. There are many uncertainties for a range of intertwined impacts that affect agricultural systems differently (Garrett et al. 2017). Impacts vary by geographical, bio-physical, and socio-economic conditions, which render it difficult to make decisions regarding the development of the sector.

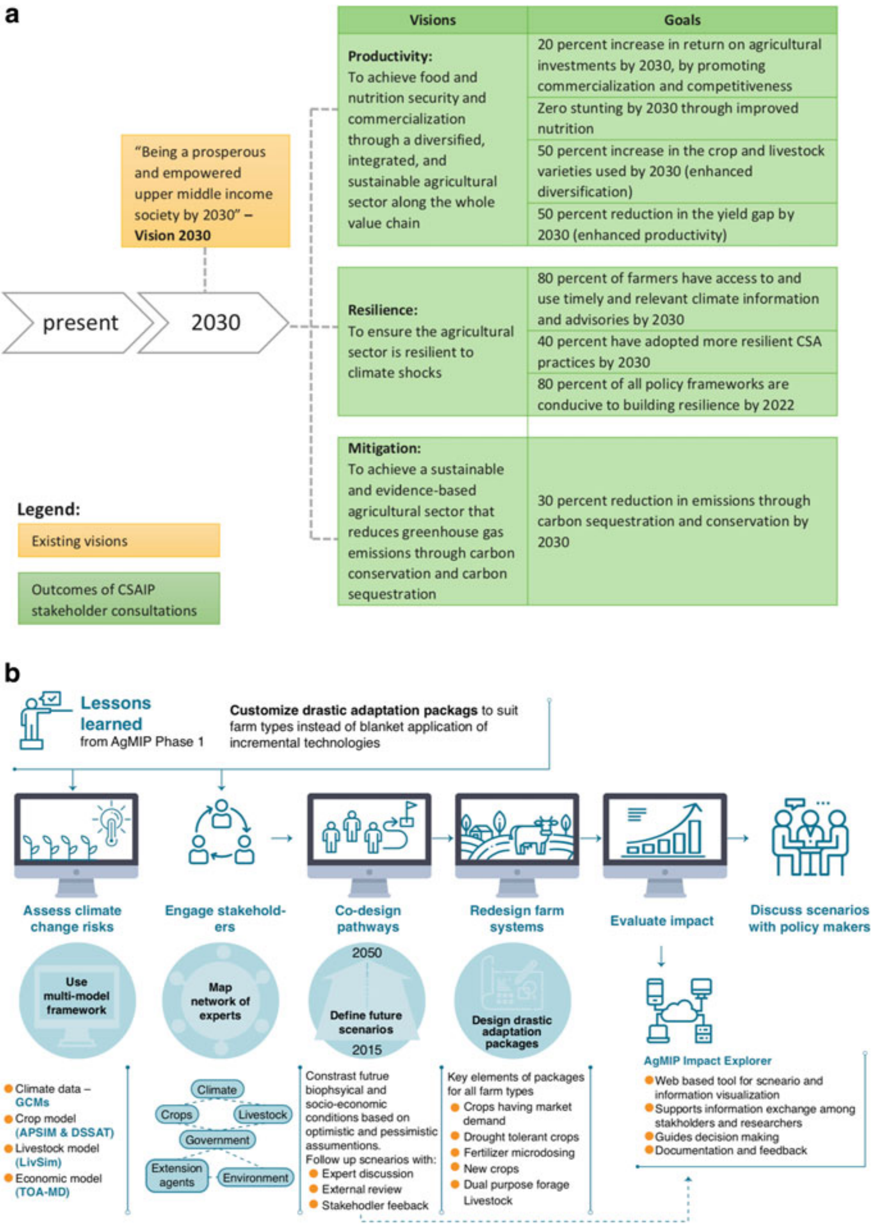


Fig. 1 **a** Vision and goals to achieve Zimbabwe's' vision 2030, as defined by the climate smart agricultural investment plan (World Bank 2019). **b** Customized climate change adaptation packages to suit particular farming systems, AgMIP RIA process. *Source* Adapted from ICRISAT (2016) and Valdivia et al. (2019)

Stakeholders and policy makers need better decision-making support that allows them to make effective investment (Bößner et al. 2018; Holman et al. 2019). Risks and uncertainty are however difficult to digest for decision processes. Strategies and programs must reflect the needs and priorities of the agricultural sector. Available information on climate dynamics and climate change impacts is however often not appropriate or available for guiding decision processes on agricultural policies and investments (Hansen et al. 2011). Given the complexity of problems in the agricultural sector, generating supportive evidence is difficult. There are influences by the multiple goals from within the sector and also other sectors, and inconsistencies in the implementation of policies from national to local levels. Most studies on climate change impacts focus on single technologies and interventions, e.g. crop or livestock species, and come up with aggregated outcomes. Neither do they measure climate change impacts on farming systems and agro-ecological zones; hence, they do not represent vulnerability adequately.

Most approaches for collecting information on climate change impacts and vulnerability fail to adequately represent the heterogeneity of the sector, and hence are not suitable to inform targeted climate change adaptation. Furthermore, they mostly consider the impacts of climate change under current conditions, but do not figure out the likely influence of future socio-economic and bio-physical conditions.

Agricultural Development Pathways for Science-Based Policy and Decision Making

To prepare for an unknown future, agricultural development pathways in combination with farming systems modelling can inform likely impacts of climate change, within given national policies, and how those national policies impact on climate change responses (Whitbread et al. 2010; Antle et al. 2017). AgMIP Representative Agricultural Pathways (RAPs) provide qualitative and quantitative information to characterize the state of a future World under which a particular farming system might operate (Valdivia et al. 2015, 2020).

The RAPs co-design process brings science and policy development closer together to inform what investments, institutional mechanisms and capacity would be needed to support an envisaged future, while acknowledging that there are uncertainties. Evaluation of possible policy decisions and adaptation measures using simulation experiments makes it possible to compare both short and mid-term adaptation strategies, at local and national scales. This provides critical insight for the design of policies, how they can meet sustainable development goals, mitigation and adaptation objectives.

The AgMIP RIA approach uses 6 critical principles:

1. **Coherent framework** to describe how the future of agriculture might look like. Given uncertainty there is need to present plausible future World conditions, based on robust assumptions. Here we compare different pathways and integrate multiple methods to assess most plausible changes in future. Global emission (Representative Concentration Pathways, RCP) and socio-economic scenarios (Shared Socio-economic Pathways, SSPs) provide global trends and parameters,

which influence local context specific projections, as defined in the RAPs. This acknowledges that global drivers impact on local action. The IMPACT global economic model provides price and productivity trends. Climate, crop, livestock and economic models integrate multiple components to represent local farming systems. They simulate farming systems changes and climate impacts under current as well as under future conditions, in this case by 2030.

2. **Science in collaboration with stakeholders and experts** to integrate science with local knowledge, through learning processes. Experts and stakeholders from different disciplines bring intrinsic knowledge about causalities and relationships to create future worlds that represent real possible change, which modeling alone cannot comprehend. Generating inputs for and revising outputs with experts also brings out more comprehensive explanations, e.g. why technologies were not being taken up, what underlying causes needed to be addressed, how the results could help to match prioritizing interventions with future conditions and needs, how research could help accelerating decision processes.
3. **Impact assessment and trade-off analyses** to project likely impacts of policy packages and adaptation interventions under future conditions with climate change. Decision makers might want to know about the levels of vulnerability of different parts of the communities along different development pathways, what interventions can provide sustainable benefits to farmers and other agriculture sector stakeholders, what are the likely consequences and what incentives are needed to achieve broad adoption of sustainable agricultural approaches, which might pan out differently in other agro-ecological regions.
4. **Delineating areas with similar response to climate change** to reduce complexity and provide suites of adaptation packages for geographical areas with similar conditions and climate change impacts. This requires characterizing areas and production systems that are more vulnerable to climate change, identify hot spots of climate change and their distribution, and how they would affect farming systems.

Methodology

The AgMIP Regional Integrated Assessment (RIA) follows a rigorous protocol based multi-model approach (climate, crops, livestock and economics) to improve information for actionable decisions that make agricultural systems more resilient to climate change. It measures changes in farm components, on individual farms and how they are distributed in heterogenous farm communities. That helps to understand better how agricultural systems could respond to climate change under future bio-physical and socio-economic conditions.

Participatory and modelling methodologies are used to measure the likely vulnerability of agricultural systems to climate change, and the possible impacts of adaptation strategies on those systems (Valdivia et al. 2015, 2020). Linking the analyses to national and global scales helps to understand, for instance, how inconsistency in the implementation of national policy interventions, as well as global markets and programs, might affect these systems (O'Neill et al. 2017).

What makes the approach unique is that it allows policy and decision makers to develop and test specific questions and story lines on investments and interventions ex ante, e.g. which populations are most vulnerable, what adaptations would benefit most farmers while building a more sustainable agricultural system, and what technology, institutional and policy gaps need most urgently to be addressed.

In Zimbabwe, AgMIP-RIA was implemented as part of a journey of multiple projects and collaborations (Masikati et al. 2013; Homann-KeeTui et al. 2013, 2020; Dube et al. 2014). Building on lessons, networks and data through earlier crop livestock projects was clearly an advantage for contextualizing the results. Initial AgMIP-RIA multi-modeling experiments, following a Business As Usual pathway with isolated technical improvements (fertilizer application, improved varieties, forage production) showed limited impact on poverty reduction, economic gains and overall livelihoods improvement (Masikati et al. 2015). The interventions increased agricultural production and food security, however, remained insufficient to meaningfully improve smallholder livelihoods. The research team therefore engaged with stakeholders and experts in another cycle to develop more transformative pathways and adaptation strategies to be tested using the AgMIP modeling approach.

Figure 1b summarizes the 6-steps:

1. **Assess climate risks**: The multi-model framework was set up for the mixed crop livestock systems in Nkayi district. It links climate models (5GCMs with contrasting temperature and rainfall, under RCP 4.5 (low emissions) and RCP 8.5 (high emissions); Ruane and McDermid (2017), with crop models (DSSAT and APSIM; Jones et al. 2003; Holzworth et al. 2014), a livestock model (LIVSIM; Descheemaeker et al. 2016), and an economic model (TOA-MD; Antle et al. 2014; Antle and Valdivia 2020a). Household data were used from an earlier baseline surveys (n = 168) to identify farm types and farm management parameters (Homann-KeeTui et al. 2015, 2020). Global price and productivity trends were taken from IMPACT projections (Wiebe et al. 2015). Experimental data were used to calibrate the crop and livestock models (Masikati et al. 2013; Descheemaeker et al. 2018).
2. **Engage stakeholders**: Stakeholders and experts from multiple disciplines were involved at early stage. The purpose and activities were shared early in the process, building on what had been done before. Researchers, stakeholders and experts co-designed the pathways and adaptation packages and analyzed simulation results and their meaning. This iterative process provided valuable inputs to modify or adjust model parameters and for validation of simulation results. Stakeholders also advised on how best to endorse the research in national planning processes. National research and government organizations were part of the team, as part of building capacity on applications for future uses.
3. **Co-design pathways**: A Business as Usual Pathway and 2 contrasting pathways, sustainable and non-sustainable development, were co-designed. In a series of 2-day workshops, engaging 10 provincial-level experts, the likely changes

(direction and magnitude) of key drivers anticipated by 2030 were identified and quantified, for each pathway. Quantitative parameters (family, farm and herd size, input and offtake levels), global prices and productivity trends, were fed into the simulation models. The process of developing RAPs narratives and storylines helped to identify policy priorities for sustainable agricultural systems.

4. **Re-design farming systems**: Typical agricultural systems and farm types were characterized. Climate change adaptation packages were developed with experts, taking into account future temperature, rainfall, water, soil nitrogen content and CO_2. Adaptation packages were verified with rural communities and local stakeholders to ensure that they respond to context specific conditions and were realistic. Taking into account complex changes, participants were asked to imagine future worlds where barriers had been removed, as the conditions for farming would have been improved over time.
5. **Evaluate impacts**: In an iterative process, modeling results were illustrated to stakeholders and experts. Impacts of climate change and the potential benefits of the adaptation packages to the farm types under different development pathways were discussed. Key messages were generated and prepared to be presented in user friendly formats. Data and story lines and results are available in AgMIP's Impacts Explorer, a web-based platform available to users (http://agmip-ie.wenr.wur.nl/home2).
6. **Discuss scenarios with policy makers**: The contrasting scenarios on what could happen under different future conditions were discussed with policy makers to identify and endorse policy and intervention priorities that lead to transformation of farming systems towards more sustainable development. Contrasting the pathways helped to bring out critical steps.

This 6-step approach can be adjusted to specific needs. There can be need for revision after dramatic changes in the socio-political environment or unexpected shocks, e.g. COVID-19 or a sudden government and regime change.

Drylands in Zimbabwe: Impacts of Climate and Climate Change Adaptation

Current Farming Systems

Land use in Nkayi district is extractive and dependent on nutrient depleted sandy soils with limited response to soil amendment. Higher temperatures, deficit rainfall and delays in the start of the rainy season make agriculture more risky.

Farmers grow mostly maize, with yields below 1t/ha (Homann-KeeTui et al. 2015). Agricultural productivity is low, and with production levels harvest outfalls are endemic. Only few farmers invest in livestock feed, despite feed shortages. Most farmers are resource poor (extremely poor farmers: 43% of the population, with no cattle, and on average 1.4 ha land; poor farmers: 38% of the population, with 5.4 Tropical Livestock Units (TLU) and 2 ha land). The other farmers are 19% of the population, with 13.9 TLU livestock and 2.7 ha land.

Unless government, financial partners and support agencies create a more conducive environment for agriculture and market oriented support systems, climate change means greater food and nutrition insecurity for large parts of the population. Potential success depends on changing the deeper structures in the agricultural set up and not on technical change alone.

Sensitivity to Climate Change Impacts

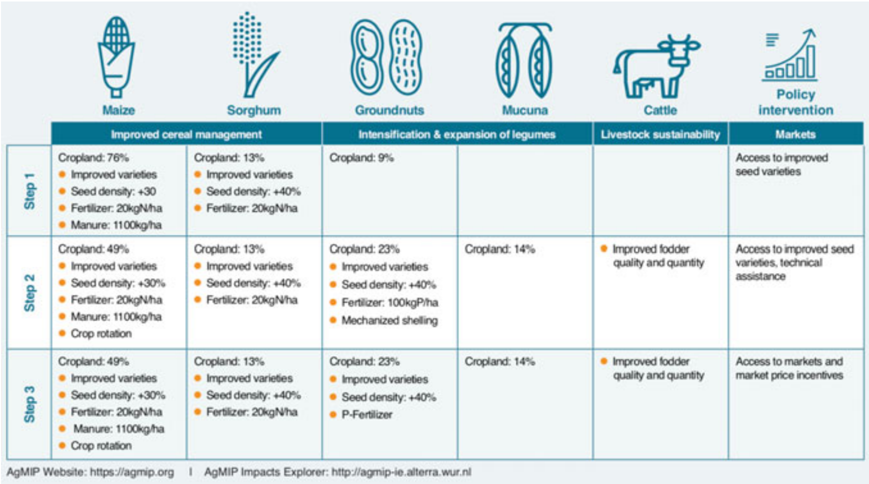
Climate projections vary by climate models and location reflecting uncertainty on how climate change impacts could pan out (Moyo et al. 2018). The projections of contrasting climate models were averaged to come up with recommendations for climate change adaptation. In this case, the climate projections to 2030 foresee increased temperatures by 2–3%. Precipitation projections are more variable, a decrease in rainfall of 25% seems possible. Furthermore, climate risks vary by crop type, crop types being differently sensitive to these changes in climate. Maize was most sensitive (−25 to 6% change in maize yield); sorghum and groundnuts varied similarly (−21 to 13% and 18% change in sorghum and groundnut yield, respectively). Cattle production was highly sensitive to climate impacts (−8 to −1% change in offtake, −22 to −4% in milk production) due to the compounded effects of climate change, reduced crop biomass production and reduced biodiversity on rangelands compromising feed quality.

Benefits to Adaptation

Farmers extremely vulnerable to climate change have greater potential for improving their livelihoods (Homann-KeeTui et al. 2020). Adaptation packages were designed assuming that various barriers to adaptation such as access to seed, markets, knowledge and services, were removed or improved. The packages were designed and evaluated assuming different degrees of implementation and considering the different farm types. Figure 2 summarizes the 3 step adaptation packages:

- Step 1 improved cereal management
- Step 2 Intensification and expansion of legumes
- Step 3 Improved feed for livestock and increased commodity prices as incentive for farmers to make these investments.

Highest returns were obtained with the full implementation of the adaptation package (step 3, Fig. 3). The majority of farms would find it economically advan-


	Maize	Sorghum	Groundnuts	Mucuna	Cattle	Policy intervention
	Improved cereal management		Intensification & expansion of legumes		Livestock sustainability	Markets
Step 1	Cropland: 76% • Improved varieties • Seed density: +30 • Fertilizer: 20kgN/ha • Manure: 1100kg/ha	Cropland: 13% • Improved varieties • Seed density: +40% • Fertilizer: 20kgN/ha	Cropland: 9%			Access to improved seed varieties
Step 2	Cropland: 49% • Improved varieties • Seed density: +30% • Fertilizer: 20kgN/ha • Manure: 1100kg/ha • Crop rotation	Cropland: 13% • Improved varieties • Seed density: +40% • Fertilizer: 20kgN/ha	Cropland: 23% • Improved varieties • Seed density: +40% • Fertilizer: 100kgP/ha • Mechanized shelling	Cropland: 14%	• Improved fodder quality and quantity	Access to improved seed varieties, technical assistance
Step 3	Cropland: 49% • Improved varieties • Seed density: +30% • Fertilizer: 20kgN/ha • Manure: 1100kg/ha • Crop rotation	Cropland: 13% • Improved varieties • Seed density: +40% • Fertilizer: 20kgN/ha	Cropland: 23% • Improved varieties • Seed density: +40% • P-Fertilizer	Cropland: 14%	• Improved fodder quality and quantity	Access to markets and market price incentives

AgMIP Website: https://agmip.org | AgMIP Impacts Explorer: http://agmip-ie.alterra.wur.nl

Fig. 2 Climate change adaptation packages developed for Nkayi district. *Source* Adapted from Valdivia et al. (2019) and Homann-KeeTui et al. (2020)

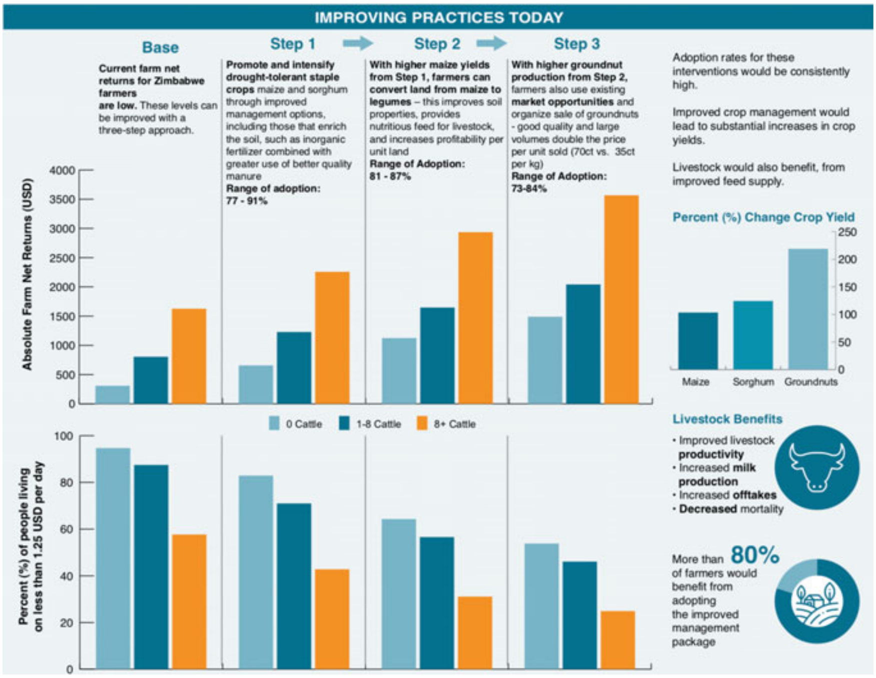


Fig. 3 Impact of adaptation options on different farm types. *Source* Adapted from AgMIP (2017)

tageous to adopt the packages, increased crop production and integration with livestock, along with market improvement. Technically, climate change adaptation can substantially improve agricultural production, if inputs and services are given and coupled with market mechanism.

For extremely poor farmers, without livestock, promoting legumes was most important as a way to increase the net returns per unit farm land, balance the negative climate change effects on maize, and sustain nutrition. For poor (<8 cattle) and non-poor farmers (≥8 cattle) with the highest risk for cattle production converting land from maize to fodder legumes would counteract climate change impacts.

Agricultural Development Pathways

Development pathways project conditions to the future, where we can assess the impacts of climate change and adaptation under those conditions. Stakeholders and experts co-designed contrasting pathways that Zimbabwe could take: what if Zimbabwe followed a sustainable inclusive economic development, or alternatively what if a priority was given to an economic growth fossil fuel intensive pathway. Analysing these futures and likely impacts, what can we learn from the pathways and what measures can be taken to ensure sustainable development and climate mitigation and adaptation goals are achieved?

Figure 4 summarizes the economic impacts of the different pathways:

Green Road—Sustainable development: Investing in a sustainable future had clear advantages: inclusive markets and access to information created incentives for all farmers to invest; farmers set more land in value, diversified and intensified crops, increased herd sizes. Policies enabling infrastructure investment and development, human and institutional capacity, R&D, technical innovations and delivery services, were aligned to transform the agricultural sector.

Grey Road: Economic growth, fossil fuel intensive: This future reminded of the past, better-off large scale commercial farmers expanded and invested, whereas the many poor would rely on off-farm income, often become suppliers of cheap labour to agro-industries, and maintain small plots on for supplementary nutrition. Poverty and malnutrition increased. With low priority for environmental and social concerns, this resulted in reliance on natural resources, and caused widespread degradation.

In both futures, agricultural productivity increased substantially. However, it is important to highlight that the impacts of climate change on crops depend on soils fertility. Crop responses to climate change impacts were low on the nutrient depleted soils; yet grain yield reductions due to climate change were higher on better soils with higher nutrient supplies than on the poor soils. However, on better soils yields were higher even when reduced by climate change, as compared to poor soils, for all crops. Soil available water partially negated the negative impacts of increased temperature. Integrated soil fertility management with more organic inputs buffered and reduced the negative effects of climate change on crop production. There is hence

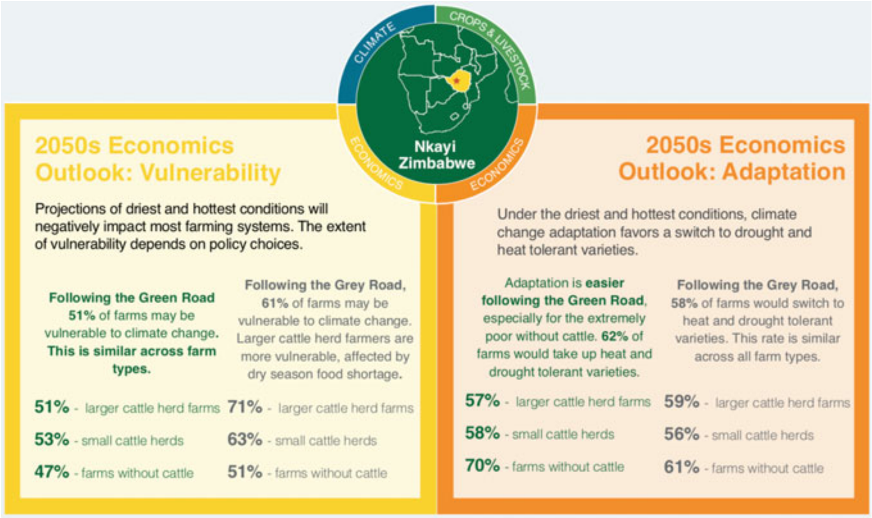


Fig. 4 Economic impacts of sustainable vs fast economic development. *Source* Adapted from AgMIP (2017)

need for holistic approaches that advance knowledge and learning about the multiple benefits and increase uptake of integrated soil fertility improvement.

Farmers with large cattle herds are most affected by climate change due to the effects of higher temperature on the biodiversity of rangelands as prime source of feed and the reduced feed quality. Supplementary feeding buffered the effects of climate change. The results highlight the utmost importance of creating decentralized feed and fodder markets, improving access to affordable stock-feed of high quality, while also investing in conservation of rangeland resources through economic incentives.

Given that in these futures agricultural productivity would increase substantially as result of more drastic agricultural investment programs, dealing with improved soil productivity and livestock feed, the main issue for climate change adaptation would be to switch to heat and drought tolerant varieties. Heat and drought tolerant varieties would benefit more under the sustainable future, and the poorest farmers would benefit more in relative terms. This is a strong argument for crop improvement programs to engage in within consultative approaches, targeting climate change and specific user needs.

An important observation was that where poverty rates are high like in the case of Nkayi district, following the sustainable development road can reduce vulnerability and half poverty by 2050. This can result in lower vulnerability and poverty, and greater benefits from adaptation, especially for the extremely poor. Investment in sustainable development supported gender equity, food security, nutrition priorities. Under the economic growth road, vulnerability would remain higher; farmers with large herds were stricken most by feed gaps. Investment in sustainable development hence paid off, it was less risky and better for the poor.

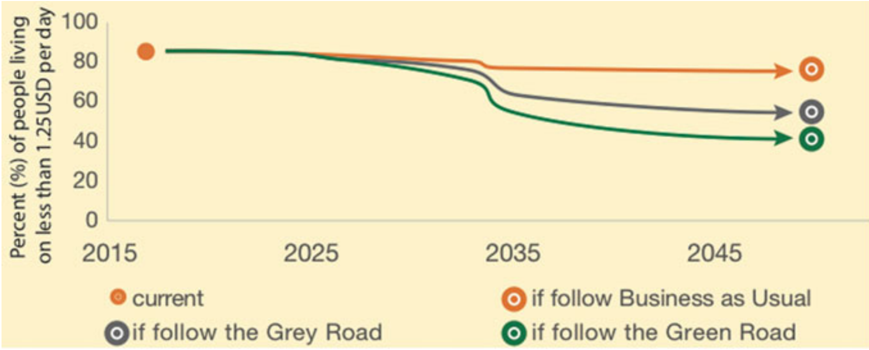


Fig. 5 Impact on poverty reduction following different development pathways. *Source* Homann-KeeTui et al. (2018)

The results also indicate that in either sustainable development or high economic growth pathway, a large proportion of farmers would remain below poverty line (Fig. 5). This means that by all means future agricultural and climate change programs have to cater better for the extremely poor. This involves creating off-farm income options, e.g. in decentralized agricultural input and output services, and improving the access to affordable nutrition and health services, to buffer their vulnerability to climate change impacts.

Discussion and Conclusions

Development Pathwaysand Trade-Offs to Support Climate Change Initiatives and Action

The strength of co-creating agricultural development pathways lies in the integration of science and stakeholder-based knowledge that yields information that enables priority setting and support to decision-making processes (Valdivia et al. 2020). Consequences of development pathways can be quantified to identify trade-offs and synergies between socio-economic and environmental outcomes. Accounting for these dimensions and complexities can accelerate transformation to sustainability (Antle and Valdivia 2020b).

Results from this study can motivate an informed dialogue through broad collaboration and engaging a broad range of stakeholders when developing national plans and help to tighten the measures required to move up from business as usual towards a sustainable development pathway (Berkes 2009; Garrett et al. 2017). The way knowledge is produced, prospective action and policy packages evaluated through ex ante impact assessments with stakeholders and experts, influences how it can serve national purposes and guide climate adaptation planning.

A major challenge lies in the availability and coordination of data that are relevant for decisions at national level and for particular farming systems. The scenario approach integrates information about farming systems and how they respond similar to climate change, at the level where climate change and adaptation happen. The learning process with local stakeholders and experts in the analyses of modeling results, can inform scaling of adaptation strategies (Holman et al. 2019).

Lessons from Using Development Pathways for Informing Adaptation Decisions

Integrated assessment approaches as shared in this chapter, development pathways with multi-disciplinary simulation models and tools, can lead to informed decision and actions, to more resilient futures for agriculture (Dimes et al. 2009; Whitbread et al. 2010, Antle and Valdivia 2020a). They help to understand how food systems might adjust in future to achieves social and environmental goods and goals, how shocks could impact those systems, and where interventions would need to set in. However, to convert modeling to action there is also need to understand what road blocks prevent using the information. For instance linear paradigms towards food security might prevent wider societal goals such as gender equity, food justice or shaping a change in attitudes towards the environment. There are also important dimensions that are not yet sufficiently being addressed, for instance, how gender, indigenous knowledge and wider environmental implications can be incorporated (Dube et al. 2017).

As much as modeling exercises have demonstrated that interventions, such as adaptation packages, can reduce yield gaps and poverty levels, the question is why these have not been implemented. One important insight was that for the many farmers at rock bottom poor state, limited yield response locked these farms at low productivity; improved management to amend poor soils is most imperative for them (Tittonell et al. 2010). Understanding the interplay between higher level and local-level drivers is critically important for developing sustainable adaptation options. Consistency between national level policy formulation and local level implementation could address some of the institutional and structural barriers to improve farming systems.

Capacitation of national staff in climate modeling and scenarios development, broadening the use of these approaches, and the learning from application and validation would be an important attribution to support national climate adaptation plans.

Priorities for Policy Support

Stakeholder and expert reflections around these pathways created urgency for policy support:

- **Building adaptive capacity**: Consultative, decentralized policies need to be implemented in a context of improved human and social capital. Infrastructure development, including seed systems and market access, ITC for digitalizing agriculture and early warning systems, are critical investments to help the high and increasing number of vulnerable smallholder farmers to adapt to climate variability and change. Considering the role women have to play in decision processes, establishing equal control over production factors remains critical; positive impacts on food security and nutrition to be expected.
- **Integrated soil fertility amendment**: Given the high risk particularly in drylands, and the need to regenerate depleted soils, promoting farmer practices of organic soil improvements and integration of crops and livestock seemed to pay off more than high levels of inorganic fertilizer. Agro-ecological approaches for enhanced soil quality would go along with crop improvement for varieties to respond to user demands, and being drought and heat tolerant.
- **Feed and fodder production**: Climate change impacts on those farmers with many cattle highlighted risks that can be mitigated through proactive promotion of feed and fodder technologies (seed availability, mechanization, decentralized feed and fodder processing and market units).
- **Revitalization of food and feed legume value chains:** Especially poor household increased their farm net returns and improved nutrition benefits through legume expansion. Considering that legume value chains have been dilapidated, ensuring functional and safe legume seed systems, production, and grain production to marketing directly benefits rural communities.
- **Confidence in promoting small grain value chains:** As drought and heat tolerant crops, nutrition dense staple, with potential strong response to management improvement, investment in production to processing technologies likely impacts rural communities positively.

Upscaling Using Agro-Similarity Approaches

An important challenge is leveraging on the uptake of technologies and caters for most critical bottleneck situations. There is need to delineate predominant farming systems for which climate impacts are similar and for which similar development pathways would be relevant. As work in process, AgMIP is working on an agro-ecological similarity approach. It maps out the distribution of most critical climate change indicators, where climatic pressure on farming systems is likely to pan-out. This involves the responsiveness of soils to climate impacts under soil fertility improvement, and the conditions under which climatic impacts would require a move towards diversified and nutrient-dense cropping systems. Complementary to the integrated assessments, this will help to identify zones of highest priority for investment in adaptation to climate change, e.g. hot spots of feed shortages, critical changes in agro-biodiversity, and bottlenecks for increasing systems productivity.

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