Climate risk analysis for adaptation planning in Zambia's agricultural sector

Supplementary Information

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A report prepared by the Potsdam Institute for Climate Impact Research (PIK) together with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), in cooperation with the HFFA Research GmbH and stakeholders from local and national governmental institutions, civil society, academia, the private sector, practitioners and development partners.

On behalf of

Potsdam Institute for Climate Impact Research

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1. Selection process for crops and adaptation options

Process

The selection process of crops and adaptation options that were analyzed as part of the climate risk analysis was driven by the following criteria:

- Alignment with national priorities
- Stakeholder priorities
- Feasibility (compatibility with crop model analysis, data availability)

To align the study focus with national priorities, we used the ten identified "Priority value chains" (maize, soybean, rice, groundnuts, potatoes, beans, millet, sorghum, cassava, wheat) and "Priority areas for adaptation measures in the agricultural sector" of the Zambian Ministry of Agriculture as the basis for the selection process. The priority value chains and adaptation measures were then discussed with stakeholders from Zambian national and local governmental institutions, civil society, academia, the private sector, practitioners and development partners who attended the kick-Off workshop on 18 May 2022 in Lusaka. Together with them, a selection of specific crops and adaptation options was made to narrow down the study focus and provide concrete results to inform long-term climate adaptation planning and investment decisions in Zambia. During two working sessions of the workshop, the selection process was discussed in six groups of stakeholders with each group having around five to eight participants. As the workshop was a hybrid event, we had also one online group comprising of around 20 participants. Each group selected two out of the ten value chains and two out of ten adaptation options that should be analysed further in the course of the study and provide reasons for their choice.

Selected crops

During the working sessions, maize (4), sorghum (3), groundnut (2) and cassava (2) were the crops most often selected. As the importance of crop diversification was emphasized during the workshop, we decided to focus on sorghum in our analysis on climate impacts on crop yields, instead of maize. However, in our analysis on crop suitability, we decided to focus on maize, sorghum and groundnut.

Selected adaptation options

In terms of the adaptation options, there was a high interest in strengthening early warning systems, as shown by the explicit selection of this adaptation option, but also through the selection of other adaptation options that relate to this topic, i.e. improving extension services with regards to using climate information for early warning and mapping drought and flood prone areas for early warning. Moreover, stakeholders prioritized conservation agriculture as an on-farm adaptation option. This led to the selection of these two adaptation options for the evaluation:

- Early warning systems: Using seasonal weather forecasts to inform climate adaptation
- Conservation agriculture

2. Global Warning Levels

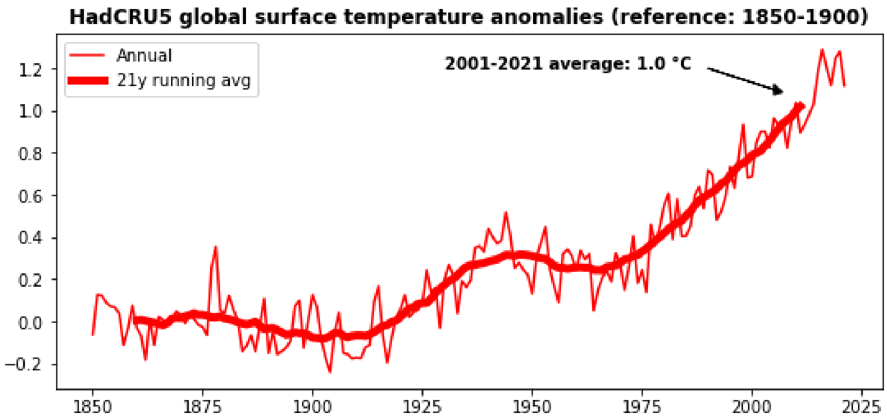

Figure 22: Global surface temperature anomalies from 1850 to 2025 compared to the reference period from 1850 to 1900 based on HadCRU5; the thin line shows annual values, whereas the thick line shows the 21year running average

Global warming levels (GWLs) are years, when certain temperature thresholds are reached by global temperature. In comparison to pre-industrial levels (1850–1900), the 21-year running average of global temperatures has crosses the 1 °C warming threshold in 2011 (2001–2021 average). Therefore, we use the 1 °C GWL as reference level to compare future warming periods to today's conditions. For each climate model, the individual years of reaching a GWL are calculated. For the analysis, the water balance indicators are extracted for 31-year time periods around these years and then averaged over the models and SSP-RCP scenarios. This approach is increasingly used in the IPCC AR6 report and helps to put results in a policy context.

3. Seasonal climate change pattern at Global Warming Levels

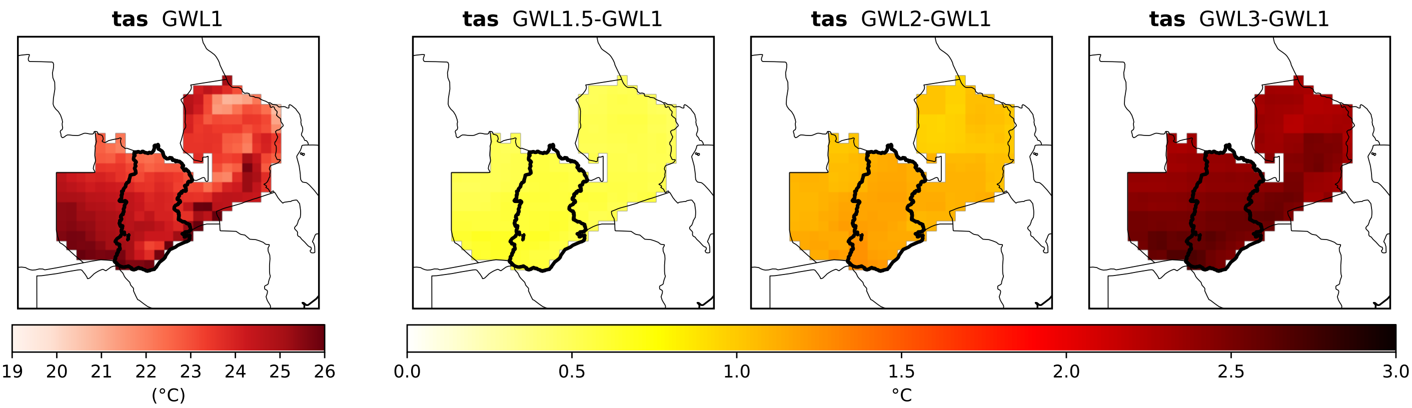

Figure 23: Average surface temperature during November- April season in Zambia at GWL 1 °C (left) and the change from GWL 1 °C to GWLs 1.5 °C, 2 °C and 3 °C

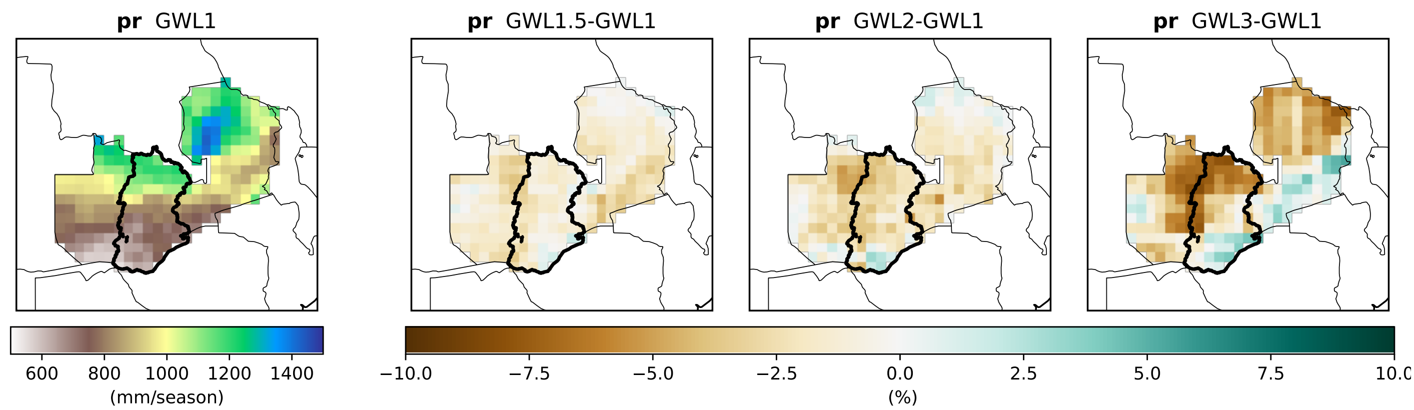

Figure 24: Average seasonal precipitation during November- April season in Zambia at GWL 1°C (left) and the change from GWL 1°C to GWLs 1.5°C, 2°C and 3°C

4. Model input and specifications for the process-based modelling with DSSAT

The following paragraphs describe the input data used for the process-based model DSSAT and the model specifications that were necessary to simulate conservation agriculture in DSSAT.

Model input for the process-based modelling with DSSAT

We used various sources of input data for parameterising and calibrating the process-based model DSSAT for sorghum yields in Zambia. We modelled sorghum yield under rain-fed smallholder conditions as this is dominant system for sorghum production in Zambia. Planting dates, harvest dates, planting depth, row spacing and plant density were obtained from the Sorghum & Pearl Millet in Zambia: Production Guide (Christiansen, 2008). The Harvest Choice (Han et al., 2015) and ISRIC (Hengl et al., 2017) soils were used as soil profiles for each grid while fertiliser applications were obtained from the SEDAC estimates of fertiliser use at grid level (Potter et al., 2010, 2012). The final modelled yield was adjusted for post-harvest losses of 33 % (13 % from harvesting, drying and threshing (Rembold et al., 2018) and 20 % from weaver bird damage (Zambia Seed Company, 2020). We use the emissions scenarios SSP1-RCP2.6 and SSP3-RCP7.0 for yield projections in the years 2030 (2021–2040), 2050 (2041–2060) and 2090 (2081–2100). Future climate projection data simulated by General Circulation Models were obtained from ISIMIP3b (Lange, 2019a, 2019b). Model validation was done by comparing simulated yields to reported district level yields in Zambia for the period 2006 to 2015 based on the Crop Forecast Survey Zambia (ZamStats, 2022).

Model specifications to simulate conservation agriculture in DSSAT

Many studies have simulated the impacts of CA with DSSAT using experimental values for model parameterization, calibration and evaluation (Dusserre et al., 2020; Lu et al., 2014; Ngwira et al., 2014; Rani et al., 2020; Worou et al., 2019). However, no studies have developed protocols for simulating the impacts of CA on yield response at a grid scale and therefore specific assumptions on the basis of the understanding on the effects of CA on soil and water dynamics in the soil were used. The following adjustments were therefore made in the DSSAT model to emulate CA across grids in Zambia:

- Animal drawn plough at 20cm depth for conventional versus tilling the planting row with a ripper
- Increased crop residue retention under conservation agriculture (Laborde et al., 2021; Nyagumbo et al., 2017)
- Increasing initial water holding capacity under CA (K. Devkota et al., 2015; Eeswaran et al., 2021; Ngetich et al., 2014)
- Increasing initial soil nitrogen (Dusserre et al., 2020; Rani et al., 2020)
- Increasing soil carbon content under conservation agriculture by 30 % (Porter et al., 2010; Thierfelder et al., 2013)
- Reducing soil erosion and increasing infiltration by adjusting runoff curves under CA (Eeswaran et al., 2021; Ngetich et al., 2014; Nyagumbo et al., 2017)

We are not considering mulching and rotations because sources and quality of external materials for mulching beyond residues are highly uncertain for smallholder farmers and that we are considering a continuous sorghum crop with a fallow period to enable long-term climate change assessment. We are also considering a CA system that reduces labour and fuel input requirements by limiting as much as possible external inputs. The DSSAT-CENTURY model was used for modelling soil organic components.

5. Input data and assumptions for the evaluation of costs and benefits of PICSA

Since PICSA has not yet been fully evaluated for Zambia, limited data is available. Hence, the following input data and assumptions are considered for the cost-benefit analysis (CBA) in order to identify the changes in market revenues and production costs associated with the implementation of PICSA:

Input data

- The CBA calculations are based on agricultural production data from the Crop Forecast Survey Zambia (ZamStats, 2022), model projections for sorghum (chapter 3.1) and cost data provided by experts from GIZ Zambia as well as the University of Reading. The cost data is based on the current GIZ piloting phase and roll-out of PICSA in Zambia as well as PICSA implementation data from other countries gathered by the University of Reading (for details on cost data, see next paragraph).
- According to Clarkson et al. (2022), the proportion of farmers making changes in their production system after a PICSA training ranges between 52 and 99 percent (with an average of 87 percent), depending on the country. In` lower wealth groups, rates of change are some times lower than in higher wealth groups due to resource constraints. For this CBA, it is assumed that the model farmer in this given scenario will change their management practices after PICSA training, which in turn will lead to an increase in income (net benefit) for the relevant smallholder farmer in Zambia.
- Climate change impacts on agriculture were approximated by projections of sorghum yields under changing climatic conditions (chapter 3.1). Thus, in our specific farm case, we assume a change in crop production. However, it should be considered that the changes made by individual farmers due to the PICSA training do not only relate to crops but – depending on their individual choices – could theoretically also relate to livestock or more general livelihood options on their farms (see Clarkson et al., 2019). Therefore, the resulting net benefits are likely to be an underestimation.

Box 1: E-PICSA – the digitized version of PICSA

PICSA is currently being piloted in Zambia as a digitized version, called E-PICSA. When describing PICSA, the terms PICSA and E-PICSA are used interchangeably here, since they are based on the same program and follow the same goals. All trainings of the extension workers are held face-to-face for both PICSA and E-PICSA. For E-PICSA, extension workers (and potentially farmers where they have smartphones) use tablets to access information and PICSA tools. This results in the extra cost of a tablet, however, the extension workers have access to digitized materials that support their capacity and enable immediate access to up-to-date climate information (historical and forecast), enhancing the speed and scope of analysis, increasing the range of coping and adaptation practices that can be considered, enabling easier exploration of budgeting scenarios (e.g. how changing input prices may effect profitability), and improving recording and monitoring to facilitate feedback and learning. The ongoing training and refresher support for extension workers is also more flexible and potentially more accessible as it can be supported with online materials.

- Net benefit data is applied from PICSA trainings conducted in Northern Ghana, as this data is not currently available for Zambia. The net benefit is taken from Lewis-Donaldson (2020); however, his model estimates the effect of only one of the multiple changes made per farmer. Thus, the resulting net benefit is most likely an underestimation. We use the percentual income change as defined by Lewis-Donaldson (2020) for Northern Ghana to apply the change in net benefit to Zambia. Although the non-digital version of PICSA (as implemented in Northern Ghana) has the same goal and overall approach as E-PICSA (as currently implemented in Zambia), its implementation differs (see Box 1) – thus, this inconsistency regarding the applied net benefit must be considered.
- To depict the discount rate that is applied in the calculations, the exponential growth rate of the Gross Domestic Product per capita of Zambia since 1971 has been applied. The discount rate amounts to 2.5 % (FAO, 2023a).
- To depict the technological change rate that is applied in the calculations, the exponential growth rate of sorghum yield in Zambia since 1992 has been applied. The technological change rate amounts to 0.27 % (FAO, 2023b).

Cost data

- The cost data from University of Reading is taken from the expert and extension worker training for PICSA in Zambia and includes data from the Zambian implementation of PICSA. It includes the cost data for trainings/refreshers for regional and national experts as well as extension workers, including cost data for the implementation of the farmer trainings and other further costs (travel costs, material, etc.). In the first year of implementation, there are costs for trainings of regional and national experts as well as of extension workers through PICSA experts, for logistics and for the planning of the workshops. In the second year, there is a refresher training for the experts and extension workers as well as the start of the trainings of farmers through the extension workers. Every five years, there are costs due to the refresher workshops for the experts and extension workers. Here, extension workers also receive new tablets, which

causes additional costs. However, these are less costly than the implementation costs in the beginning of the project. The farmers will have a refresher training in their second year after their first training. Moreover, costs of supporting partners, such as costs for the Zambia Meteorological Department (ZMD) and government staff responsible for organizing PICSA, are considered.
- Regarding travel costs, a certain amount of fuel was calculated per extension worker for the travel distances to reach farmers on the ground.
- Extension services are free to farmers in Zambia and the PICSA trainings take place near to their farms, so no travel costs for farmers are included. Thus, taking part in the PICSA training only incurs the relevant opportunity costs for farmers.

Assumptions

- The implementation of PICSA trainings incurs opportunity costs for both farmers and extension workers, for which we employ their daily income. The opportunity costs/salary for farmers and extension staff were obtained from expert elicitation.
- Overheads for extension workers visiting farmers to complete the PICSA are measured at 25 % of extension workers' opportunity costs/daily salaries for the trainings.
- It is assumed that 48 national and regional experts as well as half of all official extension workers in Zambia are trained in year one. The current total number of extension workers in Zambia is around 2389, with a certain labor market fluctuation. One extension worker is responsible for training two groups of farmers in PICSA, each group containing 25 farmers. In year two, the trainers (experts and extension workers) receive a refresher training, and the remaining half of extension workers are trained for the first time. In year three, those trainers that received the training in the second year receive a refresher.
- It is assumed that new farmers are trained until all smallholder farmers in Zambia have received training once. However, (E-)PICSA is continuously developed further and a turnover of both farmers as well as extension workers in Zambia is expected, since new farmers will start their business and new extension workers will replace the position of departing workers. Against this background, it makes sense to continue the regular training cycle for both extension workers as well as farmers during the timespan of implementation. These regular training costs are thus reflected in this CBA until 2050. However, most likely, this will still lead to an underestimation of costs, since our given data set does only calculate for regular refreshers of extension workers. but does not include full five-day training courses for any new staff. In sum, our scenario may underestimate the total costs for implementation of PICSA due to missing cost data for the regular intake of a small number of new extension workers along the training cycle.
- We assume that the PICSA implementation builds upon existing structures in the Zambian agricultural sector, such as existing extension services, which brings down the costs.

Uncertainties

- We did not include or monetize the following aspects that could have potentially a concrete cost-reducing effect for future project implementations under PICSA:
  - First, a 'multiplier and networking effect' could unfold by implementing a 'training of trainers' approach together with representatives from NGOs, farmers associations and other relevant institutions. Here, a reduction of training costs can be achieved by strengthening and multiplying the knowledge transfer via PICSA through relevant networks on the ground.
  - Second, farmers will most likely informally share the information that they received during the PICSA training with other farmers. Due to such peer-to-peer sharing, the beneficiaries could go beyond the amount included in this cost-benefit analysis, meaning that the general benefit of the PICSA training for farmers in Zambia may be underestimated (see also Clarkson et al., 2019).
  - Thirdly, a 'South-South cooperation effect' could lead to a reduction of travel costs in the mid- to long run since national and regional experts on the PICSA method could physically relate to their learning groups via shorter geographical distances. This, however, requires a stronger focus on regional expertise and capacity building.
- We did not include the following aspects, which could have potential negative costs effects or externalities resulting from the implementation of PICSA:
  - Regarding the production of sorghum, one possible cost not yet included in the analysis is increased productivity due to land expansion by the farmers. If such expansion is done at the expense of natural habitats, this should be included as a negative externality. The loss of natural habitats could lead to a loss of biodiversity, land degradation or other negative ecological consequences in the mid- to long run, followed by several negative economic impacts for regional farmers and their agro-ecosystems.
- The digital access by farmers to local climate and weather conditions through smartphones effects the results of the PICSA implementation. It must be stressed that the owning of smartphones is not necessary for the implementation of E-PICSA. Consequently, for this CBA, the ownership of smartphones by farmers has not been assumed. However, piloting projects with smartphone access by farmers are planned for the near future. Such potential digital access to modern climate information systems can be a huge advantage for farmers on the ground, leading to a more efficient implementation of PICSA and thus even greater benefits. At the same time, the buying and maintenance of smartphones and user fees represent further costs to be observed for the farmers.
- We do not distinguish between gender-specific costs and benefits. However, for future analysis, gender-disaggregated data should be used to assess gender effects of knowledge transfer via PICSA. Former studies could show that women more often lack adequate access to financial means to implement their identified adaptation measures when compared to men (see Nsengiyumva et al., 2022).

6. Assumptions on pre-arranged finance instruments considered in the protection gap estimation

Instrument	Value	Reasoning
ARC risk pool	$1 million	Had the current policy been in place over the last 20 years, this amount would have been the average annual pay-out.
Insurance (micro-level)	$2.325 million	Based on estimations of average pay-outs, average annual agricultural losses, and percentage of smallholder farmers being insured
DMMU budget	$1.0 million	Based on the assumption that the average annual budget allocation towards Disaster and Humanitarian Operations Management fully supports disaster response and recovery efforts in relation to both flood and drought
Food Reserve Agency	$4.2 million	Estimated average annual value of grain provided for free to DMMU and Ministry of Education. Value of grain sold directly to the community excluded as the extent to which these sales are made at below market prices is unclear
Contingency Fund	$8.9 million	Based on the assumption that 50 % of the typical contingency fund amount of 300 million Kwacha would typically be made available to support disaster recovery and response

Source: (GIZ, 2023)

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