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Potsdam Institute for Climate Impact Research

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Climate Risk Analysis for Identifying and Weighing Adaptation Strategies for the Agricultural Sector in Northern Ghana

- A Study at District Level in the Upper West Region –

Factsheet on the study approach and methods

Supplement to a study prepared by the Potsdam Institute for Climate Impact Research (PIK) for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), in collaboration with the Department of Planning and Land Management at the University for Development Studies (UDS) and the Resilience Against Climate Change (REACH) project.

This factsheet presents the key analysis steps of the climate risk study, explaining the different methods, models and data used. Further information can be found in the full climate risk study as well as in the supplementary material to the study.

Study background

With climate change affecting the agricultural sector in northern Ghana, putting livelihoods at risk and dampening economic growth, effective climate change adaptation is essential now and in the light of future climate impacts. Climate impacts show high spatial variations. However, decision-makers on district and regional level have to cope with limited information on climate risks on a local scale as well as on the effectiveness of adaptation strategies in specific regions. A better understanding of projected climate impacts and possible adaptation benefits on a local scale is important to guide, incentivise and accelerate public and private sector investments for climate-resilient agricultural development.

The high dependency on agriculture and the short rainy season place northern Ghana in an especially vulnerable position within the country. The climate risk study at district level is thus conducted in the Upper West Region (UWR). It focuses on the three districts Lawra, Sissala East and Wa West (see figure 1) to cover a range of biophysical, economic and social conditions.

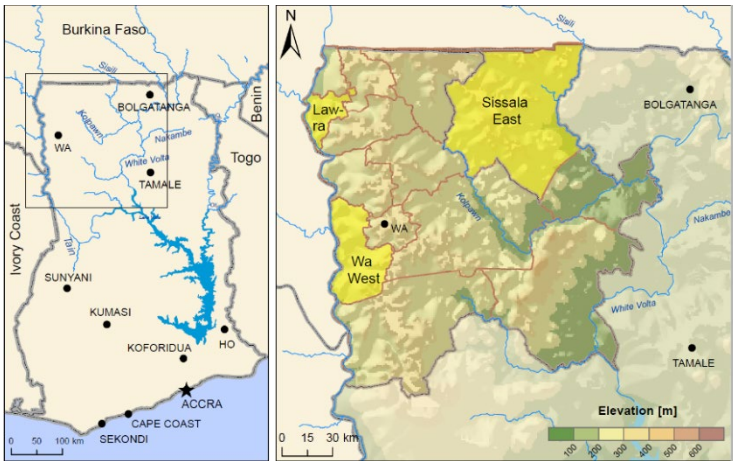


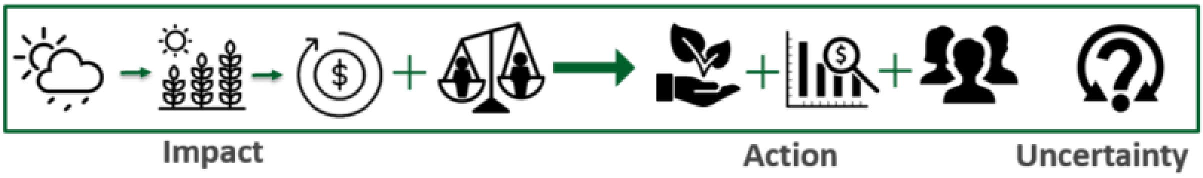
Figure 1: Map of Ghana (left) and the Upper West Region including the three districts Lawra, Sissala East and Wa West (right).

Study objectives

The study results provide decision-makers in the UWR and beyond with localised information on current and future climate risks for the agricultural sector. Costed adaptation scenarios, based on state-of-the-art climate risk modelling, as well as concrete recommendations on adaptation strategies, support adaptation planning in the region.

Study approach

The study models the impact chain from a changing climate to resulting impacts on crop production and subsequent economic consequences for the three selected districts. We analyse the influence of socio-demographic variables like gender, age, and migration status on the vulnerability to climate change to highlight the subsequent distinct needs of groups in facing climate risks. The results then feed into an action dimension to assess different adaptation strategies with regard to their risk reduction potential, their cost-effectiveness, and other socio-economic evaluation criteria, such as stakeholder interest and development co-benefits. Finally, the uncertainty attached to the results is critically discussed and recommendations targeting decision-makers are given.



The analysis utilises data from five global General Circulation Models (GCMs), a crop model and a farm level cost-benefit analysis. Information from expert interviews and literature complements the findings. The consultation of local, regional and national stakeholders through workshops and interviews ensured that the study results are suitable for the UWR and can best support local decision-makers in adaptation planning and implementation. The co-creation of the study with the University For Development Studies (UDS) supported this aim. The collaboration with the implementing REACH project creates synergies and ensures the usability and uptake of the study results. Thereby, the results can be integrated into project activities of REACH, such as the conservation agriculture (CA) manual and curriculum.

Methodological innovation and value added

The climate risk study provides a scientific and standardised analysis for adaptation action in the agricultural sector in the Upper West Region and beyond. Thereby, it combines several innovative elements:

- Modelling the impact chain: A detailed quantitative analysis of climate risks in the agricultural sector under different emissions scenarios is taken up in a comprehensive, model-based adaptation assessment, including economic potentials, to select suitable and effective adaptation strategies under future climate change projections.

- "State of the art" climate impact modelling: The climate risk analysis is based on "state of the art" climate impact models. In particular, data from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) are used, which are at the forefront of climate impact modelling.

- Quantification of climate change impacts on the agricultural sector: An important component of the risk analysis is the projection of yield losses of the key staple crops in the Upper West Region as well as the resulting production losses and crop suitability changes.

- Combination of bottom-up and top-down elements: While the climate risk analysis is mainly model-based, input from relevant Ghanian stakeholders on national, regional and district level was collected and integrated into the study at several important stages, especially with regard to selection and assessment of the adaptation strategies.

- Stakeholder engagement and consultation in Ghana: The consultation and inclusion of relevant stakeholders from Ghanaian local and national governmental institutions, civil society, academia, the private sector, practitioners and development partners in the study process supported local ownership of the results and facilitated the transfer of the findings into actions (see next section on stakeholder engagement).

- Concrete recommendations for action and investment: Based on the climate risk study, specific recommendations for adaptation action and investment as well as for transforming agriculture to become more resilient under future climate projections are provided and can inform national and local governments as well as practitioners and the German and international development cooperation.

- Scalable results: While this study focused on the Upper West Region, the results can be transferred to areas beyond. Especially the similar climate conditions in the whole of northern Ghana and southern Burkina Faso set the base for upscaling the results to these regions.

- Consideration of differential vulnerabilities and adaptive capacities: Farmer's vulnerability to climate change and adaptive capacity depends on social characteristics like gender, social class or age. This was integrated into the study ensuring that the provided recommendations can support to decrease differential vulnerabilities.

- Results at district level: Fine-grained climate and agricultural data and a farm level cost-benefit analysis lead to results tailored to the specific districts and region.

Collaboration with partners

Acknowledging the limitations of doing an adaptation assessment without being on-site, PIK sought collaboration with two partners to ensure the usability of the study results and to integrate knowledge and data from different local perspectives. The first partner, the University for Development Studies (UDS), provided scientific support throughout the study including conceptual inputs, data collection, facilitation of the stakeholder engagement, literature review and conduction of interviews. The second partner is the Resilience Against Climate Change Project (REACH), which is an EU and BMZ funded development project that is implemented by GIZ and the International Water Management Institute (IWMI) in cooperation with MoFA between 2019-2024. The climate risk study highly profits from the in-depth data collection that has been done within the REACH project and from the local network that REACH has built. The study results can in return contribute to steering the decisions within the REACH project, specifically, they will feed into the development of conservation agriculture manuals and curriculum trainings.

Stakeholder engagement

Relevant stakeholders from Ghanaian local and national governmental institutions, civil society, academia, the private sector, practitioners and development partners were engaged throughout the study. During two workshops in Wa and one in Accra, the stakeholders were informed about the study process and contributed with conceptual inputs and technical expertise as well as local insights. At a kick-off workshop in Wa, the study design was presented and the stakeholders actively steered the foci of the climate risk analysis, by specifying, contextualising and prioritising the adaptation strategies to be analysed in the study. During the actual study phase, the research team interviewed 11 stakeholders in order to integrate local knowledge into the report, which proved especially useful for the assessment of the usability of analysed adaptation strategies in the Upper West Region. In the final stages of the study completion, a validation workshop was conducted with the abovementioned Ghanian stakeholders in order to discuss the study results and to identify entry points for their uptake.

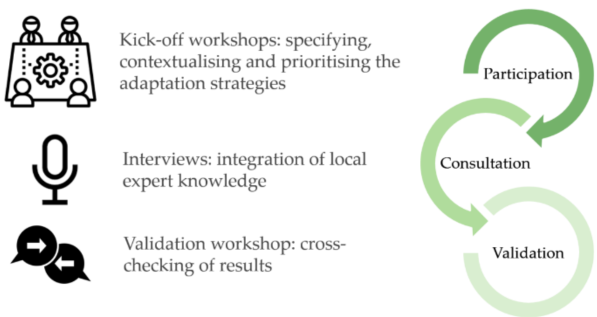


Figure 2: Stakeholder engagement followed throughout the study.

Selection of adaptation strategies

Ensuring the relevance and suitability of the adaptation strategies to be analysed, the research team developed a process based on selection criteria combined with a stakeholder prioritization and specification. A preselection of nine adaptation strategies was done according to (1) their potential to mitigate the analysed climate risks, (2) their suitability for the cost-benefit analysis and biophysical analysis with crop models, and (3) their prominence in relevant adaptation and climate change policy documents in Ghana. Screened policy documents included: Medium-term agriculture sector investment plan, National climate change adaptation strategy, Integrating Climate Change and Disaster Risk Reduction into National Development, Policies and Planning in

Ghana (2010), Ghana's Second Communication to the UNFCCC (2011). During a stakeholder workshop, the preselection of nine adaptation strategies was validated and concretized. Finally the stakeholders were selecting the four final adaptation strategies to be analysed within this study.

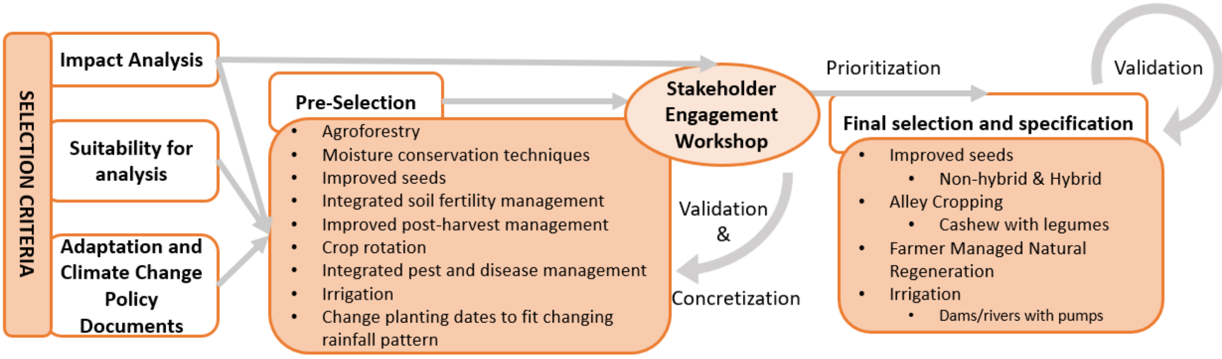


Figure 3: Selection process for the adaptation strategies to be analysed.

Data and methods

This section gives an overview of the methods and data used for the different steps of the analysis that are part of the climate risk analysis, presented in chronological order according to the chapters of the study. Throughout the study, two CO_2-emission scenarios were used as input scenarios for projecting future climatic changes: the low-emissions scenario SSP1-RCP2.6 (Representative Concentration Pathway), which is in line with the trajectory set out in the Paris Agreement, and the high-emissions scenario SSP5-RCP8.5, which is consistent with a scenario without climate policy.

Changing climatic condition: Based on SSP1-RCP2.6 and SSP5-RCP8.5, changes in climatic conditions for the Upper West Region were analysed for 2030, 2050 and 2090, as averages over 20-year periods, in reference to 2004. The analysis comprises long-term annual mean temperature, the number of very hot days and very hot nights per year, potential evapotranspiration, long-term annual mean precipitation, heavy precipitation events, and onset of the rainy season.

The simulated past and projected future climate data was obtained from ISIMIP3b (Inter-Sectoral Impact Model Intercomparison Project) data (Lange, 2019a, 2019b). The ISIMIP was created to offer a framework for the comparison of climate impact projections in different sectors. The data were bias-adjusted[1] with the observation-based W5E5 data (Lange, 2019b; Cucchi *et al.*, 2020). Historical simulations cover the years 1861-2014 and projected simulations cover the years 2015-2100. All data sets have a spatial resolution of 0.5° x 0.5°, corresponding to approximately 56km x 56km in northern Ghana. The ISIMIP data used in the study consists of five global General Circulation Models (GCMs): GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0 and UKESM1-0-LL. The data was analysed for the two emissions scenarios SSP5-RCP8.5 and SSP1-RCP2.6. Additionally to ISIMIP3b data, the results of six Regional Climate Models (RCMs) of the Coordinated Regional Climate Downscaling Experiment (CORDEX) were analysed under the same two emissions scenarios. The six models comprise the two RCMs REMO and RegCM that are downscaling the three GCMs HadGEM2-ES, NorESM and MPI-ESM. The higher resolution of the RCMs allowed for more fine-grained results and helped to verify the results of the ISIMIP3b data at the district level. Due to the unsuitability of the non-bias adjusted CORDEX data for impact modelling, the further impact assessment was only done with the ISIMIP3b data.

The indicators analysed in this study are: the annual average mean air temperature, the annual number of very hot days (maximum temperature above 35°C), the annual number of tropical nights (minimum temperature above 25°C), annual average precipitation amount, heavy precipitation intensity (maximum annual precipitation event), heavy precipitation frequency (number of days exceeding the 95th percentile during the baseline period 1995-2014)[2], and shift in rainy season onset. Rainy season onset was obtained using a definition adapted from Laux, Kunstmann and Bárdossy (2008) and Stern, Dennett and Garbutt (1981). Rainy season onset is thus considered to be the first day of the year on which these three conditions are simultaneously met:

(1) At least 20 mm precipitation within 5 days,

(2) The starting day and at least two other days in this 5-day period are wet (more than 0.1 mm precipitation),

[1] Bias-adjustment methods aim to reduce systematic errors (bias) of climate models in comparison to observations. The method used to produce ISIMIP3b bias-adjusted data, adjusts the distribution of the modeled data to the distribution of the observed data while preserving the modeled trends. While the application of bias-adjustment methods is controversial, it is necessary for climate impact modelling, as the impact models are calibrated with observational data.

[2] The absolute value of this threshold depends on time and location of interest. The calculation of the 95th percentile considers only days with precipitation (defined by days with more than 0.1 mm precipitation).

(3) No dry period of seven or more consecutive days within the next 30 days.

Since multi-model ensemble medians show on average better results than single-model results, the results in the study are multi-model medians of the 10 models. All climate data analyses are based on a 20-year average, meaning that the mean annual temperature in 2030 is calculated as an average over the mean temperature between 2021 and 2040.

Climate impacts on agricultural production: To test weather influence on the Ethiopian crop production, we applied two established crop yield simulation models, a semi-statistical model developed at PIK, and a process-based crop model. Moreover, we used machine-learning ensemble crop suitability modelling to evaluate the suitability of sorghum, maize, wheat and teff under climate change projections.

For the analysis of climate change impacts on crop production in Ghana, two different models were employed: 1) the process-based crop model APSIM (Agricultural Production Systems sIMulator) (Holzworth *et al.*, 2014) and 2) the machine-learning ensemble crop suitability models. Input data are district-level yield and management data for cow peas, groundnuts, maize, and sorghum from 2014 to 2016 for which reliable management data could be compiled. Weather data are derived from W5E5. The crops were selected based on their importance with regard to the harvested area for agriculture in the Upper West Region, availability of yield data, stakeholder interest, as well as the capacity of the crop models for those specific crops.

APSIM**:** A process-based crop simulation model represents the response of crops to varying weather conditions that affect germination, growth and development of the harvested portion of the plant by incorporating site-specific soil properties, water availability and management decisions (Robertson *et al.*, 2013). APSIM is such a model that can be used to simulate in great detail the complex climate-soil-crop systems (Holzworth *et al.*, 2014). The objectives of using APSIM in this study were to use common district-level management data on the production of four crops to calibrate and evaluate the performance of APSIM for northern Ghana, to evaluate the impacts of climate change on yields of staple crops and to identify the most promising management strategies for stabilising crop production under projected climatic conditions.

Crop suitability models**:** Machine-learning ensemble crop suitability modelling was used to evaluate the suitability of land to grow cow peas, groundnut, maize, and sorghum under current and projected climate conditions. Suitability models capture the production potential for agricultural crops, since crop production is influenced by the weather signal and, as such, can be explained by dominant biophysical parameters like weather and soils (Moat *et al.*, 2017; Hummel *et al.*, 2018). The suitability models can help to identify the areas and crops where adaptation strategies are mostly required to avert the consequences of a predicted decline in climatic suitability of the crops. Nine biophysical parameters[3] were used in modelling the suitability of four crops under current and future climatic conditions. An ensemble model consisting of machine learning algorithms was fitted using the points from the districts which, based on observed data, were determined as suitable and the stack of the nine environmental variables (seven weather-based and one soil organic carbon) with sampling for pseudo absences, performing three model runs for each. Nine different models were used which are Maximum Entropy (MAXENT), Generalised Boosted Models (GBM), Generalized Linear Models (GLM), Random Forest (RF), Generalized Additive Models (GAM), Flexible Discriminant Analysis (FDA), Multivariate Adaptive Regression Spline (MARS), Classification Tree Analysis (CTA) and Artificial Neural Networks (ANN). These models were chosen based on their data requirements and the availability of crop data for the specific models.

Differential vulnerabilities: To take account of the differential vulnerabilities and adaptive capacities of different farmer groups, the concept of differential vulnerabilities is used. Social class, gender, migration status and age are explicitly analysed with an intersectional lens.

Farmers around the world and within a country are differently affected by climate change and are not equally equipped to combat climate risks, even when facing the same climatic stressors (Thomas *et al.*, 2019). Therefore, the concept of differential vulnerabilities is introduced, meaning that the vulnerability of people is differently shaped by several socio-demographic variables like gender, location, social class, ethnicity, migrant status, marital status, age and health status. On the basis of existing literature as well as insights from expert interviews and the workshops, we analysed the different vulnerabilities and adaptive capacities of farmers in the Upper West Region depending on multiple social characteristics. The intersectional approach applied thereby moves beyond looking at a single part of the identity of a person to explain their vulnerability but looks at the different intersecting characteristics of the person.

[3] The nine parameters were: 1) Total precipitation in the growing season; 2) Total precipitation between March and September; 3) Sum of precipitation in the crop sowing month; 4) Precipitation coefficient of variation; 5) Diurnal temperature range between March and September; 6) Mean temperature growing season; 7) Mean temperature between March and September; 8) Top soil organic carbon content; 9) Top soil organic carbon content in September

Assessment of adaptation strategies: In order to identify and assess the feasibility and suitability of different adaptation strategies for the agricultural sector in the Upper West Region, a multi-criteria assessment was conducted. The following adaptation strategies were assessed: Improved seeds, Farmer Managed Natural Regeneration, alley cropping of cashew with legumes, and irrigation.

A multi-criteria framework for assessing agricultural adaptation strategies for the context of the Upper West Region was used, building on the district-specific climate risks as modelled and analysed in the study, to analyse a list of ten criteria: 1) Stakeholder interest, 2) Risk mitigation potential, 3) Risk gradient (risk-independent vs. risk-specific), 4) Cost-effectiveness, 5) Upscaling potential, 6) Potential co-benefits, 7) Potential negative outcomes, 8) Barriers for implementation, 9) Institutional support requirements, 10) Differential vulnerabilities. The applied analysis builds on three different pillars: a modelling approach, a literature review and expert knowledge from local partners (Figure 3). A focus was placed on criteria 2), 3) and 4) for performance assessment based on PIK's impact models, both biophysically and economically. Indicators 2) and 3) were assessed using the crop model APSIM. In addition to the biophysical and economic indicators, the multi-criteria assessment also contained several socio-economic and institutional indicators. Those indicators were assessed based on expert and key informant interviews, an expert survey, input from three stakeholder workshops and empirical literature. In total, 11 individual experts were interviewed for the study using semi-structured questionnaires, to elicit expert knowledge regarding adaptation, vulnerability to climate change, adaptive capacity and the four selected adaptation strategies in Ethiopia. Further, the three stakeholder workshops and knowledge of our partners importantly added to the assessment. Empirical evidence on adaptation strategies in the Upper West Region was drawn from a diverse body of literature and used to complement the assessment. Indicator 10) was assessed based on the concept and the findings introduced earlier under "differential vulnerabilities".

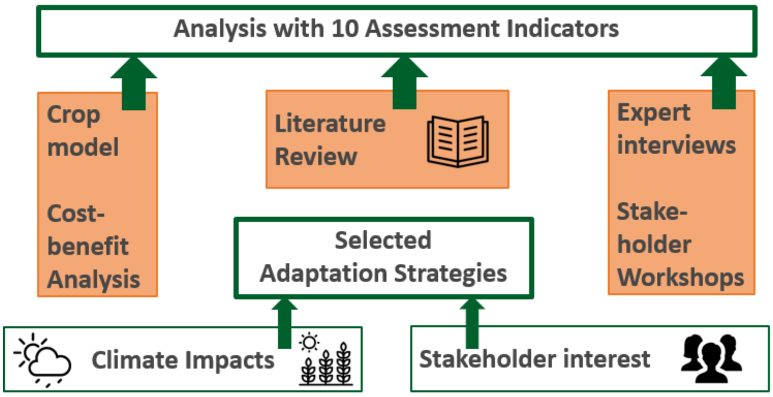


Figure 4: Design of adaptation assessment

Economic analysis of adaptation strategies**:** For analysing the cost-effectiveness of adaptation strategies in the Upper West Region, a farm-level cost-benefit analysis was done. The net present values (NPV), benefit-cost ratios (BCR) and the internal rates of return (IRR) were compared across different scenarios, namely between adaptation scenarios and non-action under different economic scenarios.

A cost-benefit analysis (CBA) is conducted to evaluate the economic costs and benefits of selected adaptation strategies at the farm level. The CBA applied examines the expected costs and benefits of implementing an adaptation strategy compared to the costs and benefits of a business-as-usual production system. Costs related to agricultural input, labour, tools and machinery are considered. Three adaptation strategies were analysed for one specific district according to the comparative agronomic, market and commercialization advantages available in each of the districts. These are: 1) Improved- and hybrid maize seeds in Sissala East, 2) Alley cropping of cashew with legumes in Lawra as a crop switch from sorghum, and 3) Irrigated tomato production during the dry season in Wa West as an additional income-earning activity to compensate for the potential yield for losses from sorghum during the main cropping season. Economic indicators such as the net present value (NPV), benefit-cost ratio (BCR) and the internal rate of return (IRR) are derived.

Several scenarios are considered for each adaptation strategy. They are a combination of the production system, climate scenario (i.e., no climate change vs. SSP1-RCP2.6 vs. SSP5-RCP8.5) and potential future socio-economic scenario (i.e., positive economic development vs. low economic development). For the baseline period, the yield, costs of production and price data are derived based on information collected from a farm survey of a minimum of three farmers per adaptation strategy. For the future alternative production systems, in the first stage, the average yield changes estimated based on the crop model simulations or literature are applied linearly from 2020 to 2040. To calculate the costs of production for the future alternative production systems, first, the costs of production for the specific production system are calculated from the farm data as it is implemented in the present. Then, costs and prices in the future are calculated based on future socio-economic scenarios. Under a positive economic development scenario, prices are assumed to increase by 30 % and costs to decrease by 10 % until 2040. Under a low economic development scenario, prices are assumed to remain the same and costs to increase by 10 %. A discount rate of 10 % is used.

Uncertainty analysis: The uncertainty attached to modelling results, methodological approaches and data quality was critically reflected to guide interpretation of the results.

The results presented in the study are subject to a number of uncertainties and limitations, which must be thoroughly considered for adequate interpretation, as well as for drawing policy implications and recommendations. The last chapter of the study discusses the uncertainties attached to the different types of analysis throughout the study and highlights their relevance in the context of the Upper West Region. Major sources of uncertainty include the different input data used, such as climate model data, crop yield data and price data. The models and approaches used also come with uncertainties attached, as they can only partially represent and project climate risk and adaptation strategies.

This factsheet is based on a study prepared by the Potsdam Institute for Climate Impact Research (PIK) for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). The study was developed in cooperation with the Department of Planning and Land Management at the University for Development Studies, the Resilience Against Climate Change (REACH) project, the HFFA Research GmbH and Ghanaian stakeholders from local and national governmental institutions, academia, civil society as well as farmers' associations. The study "Climate Risk Analysis for Identifying and Weighing Adaptation Strategies for the Agricultural Sector in Northern Ghana - A Study at District Level in the Upper West Region " builds upon the climate risk study for Ghana's agricultural sector at the national level and both studies aim at contributing to Ghana's NDC implementation and to the objectives of the NDC Partnership.

References

Cucchi, M. *et al.* (2020) *WFDE5: bias adjusted ERA5 reanalysis data for impact studies*.

Holzworth, D. P. *et al.* (2014) 'APSIM – Evolution towards a new generation of agricultural systems simulation', *Environmental Modelling & Software*. Elsevier, 62, pp. 327–350. doi: 10.1016/J.ENVSOFT.2014.07.009.

Hummel, M. *et al.* (2018) 'Reduction in nutritional quality and growing area suitability of common bean under climate change induced drought stress in Africa', *Scientific Reports*, 8(1), p. 16187. doi: 10.1038/s41598-018-33952-4.

Lange, S. (2019a) 'Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0)', *Geoscientific Model Development Discussions*. doi: 10.5194/gmd-2019-36.

Lange, S. (2019b) *WFDE5 over land merged with ERA5 over the ocean (W5E5). V. 1.0.*, *GFZ Data Services*. doi: 10.5880/pik.2019.023.

Laux, P., Kunstmann, H. and Bárdossy, A. (2008) 'Predicting the regional onset of the rainy season in West Africa', *International Journal of Climatology*. doi: 10.1002/joc.1542.

Moat, J. *et al.* (2017) 'Resilience potential of the Ethiopian coffee sector under climate change', *Nature Plants*. doi: 10.1038/nplants.2017.81.

Robertson, R. *et al.* (2013) 'Incorporating process-based crop simulation models into global economic analyses', in *American Journal of Agricultural Economics*. doi: 10.1093/ajae/aas034.

Stern, R. D., Dennett, M. D. and Garbutt, D. J. (1981) 'The start of the rains in West Africa', *Journal of Climatology*. doi: 10.1002/joc.3370010107.

Thomas, K. *et al.* (2019) 'Explaining differential vulnerability to climate change: A social science review', *Wiley Interdisciplinary Reviews: Climate Change*. doi: 10.1002/wcc.565.