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Climate risk analysis for identifying and weighing adaptation strategies in Ghana's agricultural sector

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) and in cooperation with the Ghanaian Ministry of Food and Agriculture (MoFA).

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 objective

While many countries recognize adaptation as an important component of their responses to climate change, little guidance on how to operationalize adaptation goals exists. As part of their international commitments, such as under the Paris Agreement, countries seek to develop and implement adaptation policies and investment plans, for instance as part of their Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs). Oftentimes, only limited information on climate risks—upon which climate change adaptation decisions are based—is available. This constitutes the gap climate risk analyses seek to address, by providing evidence for substantiating political commitments and planning regarding adaptation. The climate risk analysis conducted for Ghana focuses on the evolving trends for temperature and precipitation, future water availability and the suitability of land for crop production. Based on this information, adaptation strategies are selected and analysed with regard to their feasibility, cost effectiveness and aptitude for local conditions. The study results provide decision-makers in Ghana with costed adaptation scenarios, based on state-of-the-art climate risk modelling, as well as concrete recommendations for making agriculture more climate resilient. The findings can feed into national adaptation planning processes, such as within the framework of both Ghana's NAP and NDC development and review.

Study approach

The study models the full **impact** chain from a changing climate to changing water availability and resulting climate impacts on the agricultural sector. 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. The **uncertainty** attached to the results is critically discussed and an outlook with recommendations for decision-makers is given.

Throughout the study design and implementation, special attention was given to **consulting key stakeholders in Ghana** in order to ensure that the study **takes into consideration their interests** and **uses their local expertise, especially with regard to feasible adaptation options**. This was undertaken through **consultation workshops with the Ghanaian government** and **qualitative interviews** conducted with experts and key informants, such as from academia, civil society and the private sector.

Methodological innovation and value added

The climate risk study provides a **scientific and standardised analysis** for adaptation action in Ghana's agricultural sector, within the context of its NDC. 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.

- **"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 (ISI-MIP)** are used, which are at the forefront of climate impact modelling and reduce modelling uncertainty by drawing on multiple impact models.

- **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 Ghana as well as the resulting production losses, crop suitability changes and vulnerability of the agricultural sector.

- **Combination of bottom-up and top-down elements**: While the climate risk analysis is mainly model-based, **input from relevant Ghanaian stakeholders** was collected and **informed 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 Ghana** in the study process also helped to ensure **local ownership** of the results and to facilitate **uptake of the findings** in policy processes (see next section on stakeholder engagement).

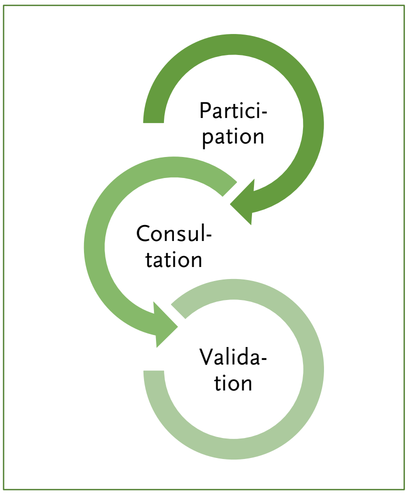
- **Based on partner country's political priorities**: The **starting point** for selecting the adaptation strategies were relevant **Ghanaian policy documents**, such as Ghana's NDC or National Climate Change Adaptation Strategy, to ensure political coherence and country ownership.

- **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 climate resilient are provided and can **inform national governments** as well as **German and international development cooperation**.

- **A scalable approach**: While this study focused on the whole of Ghana, the approach can be transferred to **different spatial scales**. For Ghana, a study at **district-level** is in progress (on request of the partner country), which will use more local datasets and focus specifically on the needs of local decision-makers and implementers of climate change adaptation plans.

Stakeholder engagement

Relevant stakeholders from government, civil society, academia and the private sector in Ghana were engaged throughout the study. They contributed with conceptual inputs and technical expertise as well as local insights during two workshops held in Accra. At a kick-off workshop, the study design and the selection of adaptation strategies for analysis within the study were discussed, especially with regard to their relevance for stakeholders and national policy processes. During the actual study phase, the research team interviewed twenty stakeholders in order to integrate local knowledge into the report, which proved especially useful for the assessment of the feasibility of analysed adaptation strategies. In the final stages of study completion, a validation workshop was conducted with the above-mentioned stakeholders to discuss the study results and to identify entry points for their uptake and integration into existing policy processes for adaptation, such as the NAP and NDC process.



Data and methods

This section gives an overview on the methods and data used for the different steps of the analysis that are part of the climate risk study, 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-emission scenario RCP2.6 (Representative Concentration Pathway), which is in line with the trajectory in the Paris Agreement, and the high-emission scenario RCP8.5, which is consistent with a scenario without climate policy.

Changing climate condition: Based on RCP2.6 and RCP8.5, changes in climatic conditions for Ghana were analysed until 2030, 2050 and 2090. The analysis comprises mean annual temperature, the number of very hot days per year, mean annual precipitation, heavy and very heavy precipitation events, shifts in the number of rainy seasons and changes in the length of rainy seasons.

The simulated past and future climate data was obtained from ISI-MIP2b data (Inter-Sectoral Impact Model Intercomparison Project). The ISI-MIP was created to offer a framework for the comparison of climate impact projections in different sectors. The data were bias-corrected with the observation-based WFDEI data (Warszawski et al., 2014). Historical simulations cover the years 1861-2005 and projected simulations cover the years 2006-2100. All data sets have a spatial resolution of 0.5° x 0.5°, corresponding to approximately 50km x 50km at the equator. The ISI-MIP data used in the study consists of four climate models: IPSL-CM5A-LR, HadGEM2-ES, GFDL-ESM2M and MIROC5 (Frieler et al., 2017). The climate variables used for the analysis are daily maximum temperature, daily minimum temperature, daily mean temperature and total daily precipitation. Since multi-model means usually show better results than single-model results, the results in the study are averages over the four 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.

Changing water availability: To assess the impacts of climate change on water resources (precipitation, groundwater recharge, actual evapotranspiration and river discharge) in Ghana, an eco-hydrological model developed at PIK was used to simulate the hydrological processes in the Volta River Basin. The model is driven by climate input of RCP2.6 and RCP8.5 from four global climate models.

The Soil and Water Integrated Model (SWIM), an eco-hydrological model developed by Krysanova et al. (2005), was used to simulate the hydrological processes in the Volta River Basin. The Volta River Basin (VRB) covers an area of 403,269 km^2 and represents about 70% of the area of Ghana. Annual absolute and relative changes in river discharge at the VRB outlet are given, as well as average monthly changes in three future periods: 2021-2040, 2041-2060 and 2080-2099. Different data inputs were used to calibrate the model: The Shuttle Radar Topography Mission (SRTM) 90m digital elevation model was used to delineate the Volta River Basin into 578 sub-basins[1]. Soil parameters were derived from the Harmonised World Soil Database (HWSD v1.0), and data on land use and cover were derived from the Global Land Cover map (GLC2000). The hydrological model was calibrated and validated using daily discharge data at 16 gauges provided by the Global Runoff Data Centre (GRDC) and a number of time series copied from hydrological yearbooks. Existing and planned reservoirs as well as water withdrawals for different purposes like agricultural and domestic use were not yet considered in the simulations, as the necessary data were not available. Therefore, the results presented in the study assume a natural hydrological system without human interference. Land use and cover are also considered to be constant without change in future periods.

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

For the analysis of climate change impacts on crop production in Ghana, three different models were employed: 1) the semi-statistical crop yield simulation model AMPLIFY (Agricultural Model for Production Loss Identification to Insure Failures of Yields), which was developed at PIK (Gornott and Wechsung (2016) and Schauberger et al. (2017)), 2) the process-based crop model APSIM (Agricultural Production Systems sIMulator) (Holzworth et al., 2014) and 3) the machine-learning ensemble crop suitability models. Input data are district-level maize yields from 1993 to 2017, provided by the Ghanaian Ministry of Agriculture and pooled in a panel to increase statistical power for AMPLIFY. Weather data are derived from ERA-Interim (Dee

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[1] A digital elevation model is a digital representation of a spatial unit's surface, for instance of a water basin, and contains the respective elevation data. Digital elevation models are important input for geographic information systems, for producing relief maps and for hydrological modelling, amongst others.

et al., 2011) except precipitation, which is extracted from CHIRPS (Funk et al., 2015). For APSIM, maize yield was simulated from 2005 to 2017 for 27 districts, which had complete maize yield records for the time period and for which reliable management data could be applied.

AMPLIFY: AMPLIFY combines statistical and process-based models using historical weather and yield data as well as remote sensing information to remotely assess crop yields and yield losses. The tool crucially differentiates between weather-related and non-weather-related (agronomic management, socio-economic) yield perils. Exogenous variables in the AMPLIFY model are different weather indices measured during the growing season. The model quality is measured by reproduction of the observed yield time series on national level, with an additional out-of-sample quality test.

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, Nelson, Thomas, & Rosegrant, 2013). APSIM is one such model that can be used to simulate in great detail the complex climate-soil-crop systems (Holzworth et al., 2014). In this present study, the module APSIM-Maize 7.1 (Brown et al., 2014) was used to simulate the yield response of maize. The objectives of using APSIM in this study were to use common district-level management data on maize production to calibrate and evaluate the performance of APSIM for Ghana, to evaluate the impacts of climate change on yield on maize and to identify the most promising management strategies for stabilising maize production under projected climatic conditions.

Crop suitability models: Machine-learning ensemble crop suitability modelling was used to evaluate the suitability of land to grow sorghum, maize, groundnuts and cassava under current and projected climate change as well as the impact of different adaptation strategies on the suitability of the land for growing these respective crops. The crops were selected based on their importance with regard to harvested area for agriculture in Ghana, availability of yield data, as well as the capacity of the crop models for those specific crops. 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 (Hummel et al., 2018; Moat et al., 2017). Since the results are spatially explicit, thus showing how results differ across regions, the suitability models identify the areas where adaptation strategies are mostly required to avert the consequences of a predicted decline in climatic suitability of the crops. Eight biophysical parameters[2] were used in modelling the suitability of four crops under current and future climatic conditions. An ensemble model consisting of nine 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 eight 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), (MARS), Classification Tree Analysis (CTA), Artificial Neural Networks (ANN) and Surface Range Envelope (SRE). These models were chosen based on their data requirements and the availability of crop data for the specific models.

Assessment of adaptation strategies: In order to identify and assess the feasibility and suitability of different adaptation strategies for Ghana's agricultural sector, a multi-criteria assessment was conducted. In addition, barriers to adaptation and the adaptation context were analysed.

A simple framework for assessing agricultural adaptation strategies for the context of Ghana was used, building on the country-specific climate risks as modelled and analysed in the study, as well as country-specific measurement and adaptation information to analyse a list of eight criteria: 1) Risk response; 2) Degree of institutional support needed; 3) Risk gradient; 4) Risk mitigation potential; 5) Cost effectiveness; 6) Upscaling potential; 7) Development co-benefits; 8) Stakeholder interest. A focus was placed on criteria 4) and 5) for performance assessment based on PIK's impact models, both biophysically and economically. Other data used for the assessment included literature reviews and expert judgment gathered through semi-structured interviews: 16 semi-structured expert interviews with a total of 20 researchers, NGO workers and private sector representatives were conducted. In addition, two stakeholder workshops (compare section on stakeholder engagement) informed the subsequent assessment, including government partners of German development cooperation. The interviews were transcribed, coded and analysed using thematic analysis following the Attride-Stirling model (Attride-Stirling, 2001) in order to identify key themes and perceptions of experts on a range of issues, such as adaptation barriers, climate vulnerability and exposure in Ghana and performance of specific adaptation strategies. In addition, key policy documents were consulted, such as the Ghana National Climate Change Adaptation Strategy, the Ghana National Climate Change Policy and Ghana's NDC. Empirical evidence on adaptation strategies in Ghana was drawn from a diverse body of literature and used to complement the assessment.

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[2] The eight parameters were: 1) Total rainfall in the growing season; 2) Total rainfall received between March and September; 3) Sum of rainfall in the crop sowing month; 4) Rainfall 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.

Economic analysis of adaptation strategies: For analysing the cost effectiveness of adaptation strategies in Ghana, the net values of crop production (NVP) were compared across different scenarios, namely between three adaptation scenarios (post-harvest management, irrigation, crop insurance) and non-action.

A comparative static analysis was conducted based on five scenarios: the benchmark scenario (BAS), the climate change scenario (CC), an irrigation scenario (IRR), a post-harvest management scenario (PHM) and a crop insurance scenario (INS). Input data included crop yield and area data (SRID-MOFA, 2018) and parameters collected, wherever possible, from the empirical literature on Ghana. Otherwise, data was collected on developing countries in general, to fill specific data gaps regarding the Ghanaian case. Specifically, the net values of crop production (NVP) were compared among the scenarios. All economic values reported in the study are based on 2010 prices[3]. The reference scenario for climate change impacts was the benchmark scenario (BAS). For all adaptation scenarios (IRR, PHM and INS), the climate change impact scenario (CC) was the reference scenario. This is because the rationale for adaptation strategies is to dampen the economic consequences of climate change. Impacts of climate change were modelled as changes in crop yields or area suitability. The impacts here refer to the changes in anticipated (counterfactual) yield and area suitability (in the 2040s) relative to the present (actual) yield and area suitability (in the 2010s). The exercise involved imposing these anticipated changes on the current crop production system. There are two channels through which climate change influences crop production: by affecting the yield per ha (impact channel one) and/or changing area suitability for crop growth (channel two, variant to the yield impacts). Both of the channels were modelled: For the yield impact channel, a 5% rain-fed crop yield loss in maize, sorghum and groundnuts was assumed at all of the three geographic scales that were considered, which was called the yield-based impact scenario (Y-CC). In the variant impact channel, a 5% decline in area suitability for each crop was assumed. Such marginal land, whose suitability to grow crops is reduced due to climate change, could sustain a maximum of 50% benchmark yields. The remaining portion of land could still maintain its benchmark yield even under climate change. This second impact scenario was called an area-based impact scenario (A-CC). All assumptions were derived from the impact modelling results as well as relevant literature. The results under the climate change scenarios represent the costs of climate change or the costs of inaction, whereas the results under the adaptation scenarios were compared to the no-adaptation case (CC) and the benchmark scenario (BAS). This is in order to account for the cost effectiveness of adaptation strategies as compared to a scenario without adaptation action or to a counterfactual world with no climate change impacts.

Uncertainty analysis: The uncertainty attached to modelling results, methodological approaches and to 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 Ghana. Major sources of uncertainty include the different input data used, such as climate model data, river discharge 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), in cooperation with the Ghanaian Ministry of Food and Agriculture (MoFA). The report aims to contribute to Ghana's NDC implementation and to the objectives of the NDC Partnership.

In contribution to:

NDC PARTNERSHIP
ACCELERATING CLIMATE
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[3] Price data from 2010 was chosen to have a consistent, relatively recent baseline with good data availability.

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