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

Supplementary Information

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1. Supplementary information on the climate scenarios used in the climate risk analysis

The future emissions scenarios used in this report, the SSP-based RCPs, are based on the new versions of Representative Concentration Pathways (RCPs) introduced for the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2022). Shared Socioeconomic Pathways (SSPs) describe possible socio-economic conditions, land-use changes, and other human-caused climate drivers that influence greenhouse gas emissions, thus affecting radiative forcing and potential future societal conditions. To translate the socioeconomic conditions of the SSPs into possible greenhouse gas emissions trajectories, different Integrated Assessment Models (IAMs) were employed (Hausfather, 2018). The IAMs include assumptions about the potential changes in population, education, energy use, technology and other factors over the next century and therefore project different emissions pathways for individual SSPs. In total, there are five scenarios, SSP1 to SSP5, which represent a range of socio-economic trajectories, covering low to high challenges for mitigation and adaptation. These different emissions pathways are grouped and represented by the seven RCPs, which are defining a radiative forcing achieved in 2100. The RCPs are labelled after the additional radiative forcing level reached in the year 2100 relative to pre-industrial times (+1.9, +2.6, +3.4, +4.5, +6.0, +7.0 and +8.5 W/m², respectively) (van Vuuren et al., 2011; Wayne, 2013). Any global concentration pathway for the 21st century can be reached under any SSP, except for RCP8.5, which may occur only under SSP5 (O'Neill et al., 2014; van Vuuren et al., 2014). In the climate risk analysis for adaptation planning in Madagascar's agricultural sector we use SSP1-RCP2.6, SSP3-RCP7.0 and SSP5-RCP8.5. The first one, SSP1-RCP2.6, is the IPCC's second-most optimistic scenario and represents a shift in society towards more sustainable practices, and a shift from economic growth to general well-being. In this scenario, the increase in global temperature is projected to be 2°C by 2100 compared to pre-industrial values. The second one, SSP3-RCP7.0, depicts high challenges for mitigation and adaptation in a world with no or little climate policy interventions and temperature increases of up to 5°C until the end of this century (Hausfather, 2018; van Vuuren et al., 2011). With an additional radiative forcing of 7 W/m² by the year 2100, this scenario is in the upper-middle part of the range of scenarios considered by the IPCC. The third scenario, SSP5-RCP8.5, represents a fossil-fuelled development with no additional climate policy. With an additional radiative forcing of 8.5 W/m² by the year 2100, this scenario represents the upper boundary of the range of scenarios considered by the IPCC (Chen et al., 2021).

2. Supplementary information on the climate projections

In this climate risk analysis, both observationally-derived historical climate data and climate-model data projecting into the future are used as input for the agricultural modelling. For agricultural model calibration, the observationally-derived W5E5 dataset is used. This dataset has global coverage in a 0.5° horizontal and daily temporal resolution and had been compiled to support the bias adjustment of climate-model derived input data for the Inter-Sectoral Impact Model Intercomparison Project Phase 3 (ISIMIP3), forming part of ISIMIP3a (Lange et al., 2021). In a second step, the calibrated agricultural model was run again with climate data from ISIMIP3b that constitute thus-bias-corrected climate model output data from the Coupled Model Intercomparison Project Phase 6 (CMIP6) for historical, SSP1-RCP2.6, SSP3-RCP7.0, and SSP5-RCP8.5 conditions (Lange, 2019, 2021). The ISIMIP3b ensemble comprises one simulation from each of ten CMIP6 models, divided into five primary[1] and five secondary[2] models, based on performance, independence, and availability criteria, which together represent well the full CMIP6 ensemble's spread in climate sensitivity (Lange, 2021). After bias-adjustment and downscaling done by the ISIMIP project, these climate data were here further downscaled to reach a spatial resolution of 0.125° × 0.125°, corresponding to about 12.5 km × 12.5 km near the equator. The downscaling of the model simulations was performed with a high-resolution observational dataset which was produced by applying the CHELSA (Climatologies at high resolution for the earth's land surface areas) algorithm to W5E5 data (Karger et al., 2022), which keeps the datasets consistent with the model calibration, while at the same time allowing for the influence of high-resolution topography on local climate (Hampf et al., in preparation a).

1 GFDL-ESM4, MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL, IPSL-CM6A-LR

2 MIROC6, EC-Earth3, CNRM-ESM2-1, CNRM-CM6-1, CanESM5

3. Crop modelling

3.1 Methodology and the EcoCrop model

The Crop Ecological and Environmental Requirements model (EcoCrop) is a process-based agricultural model that uses environmental ranges to determine the suitability of a crop to be grown in a specific location (Ramirez-Villegas et al., 2013). It compares monthly climate data with crop-specific thresholds for minimum and maximum temperature and precipitation, and also takes soil pH into account. The output of the EcoCrop model is an index that varies between 0 and 1 (0 not suitable to 1 excellently suitable). This index can be clustered into five classes: not suitable (0–0.2), marginal (0.21–0.4), suitable (0.41–0.6), very suitable (0.61–0.8) and excellently suitable (0.81–1).

For this report, soil pH maps for Madagascar were derived from global soil property maps that are publicly available at International Soil Reference and Information Centre (ISRIC-World Soil Information, 2020). For model calibration, W5E5 climate data was used and mean temperature and precipitation sums were averaged over 1986–2015, representing the baseline year 2000. The EcoCrop model was evaluated by comparing the predicted suitability areas against observed harvested area at district level. Observed harvested area of coffee, pepper and vanilla production at district level was obtained from the Malagasy Ministry of Agriculture for the time period 2005–2010. Longer time periods at district level were not available.

3.2 Methodology and the APSIMX model

Peanut yields were simulated with the next generation of the Agricultural Production Systems sIMulater (APSIMX, version 2023.8.7287.0). APSIMX is a process-based crop model that simulates the growth and development of various crop species in response to management under diverse environmental conditions (Holzworth et al., 2018; Holzworth et al., 2014). It has been widely used and tested in various studies, including model intercomparison projects of the Agricultural Model Intercomparison and Improvement Project (AgMIP, Asseng et al., 2013; Bassu et al., 2014; Müller et al., 2016). The peanut module in APSIM was developed by Robertson et al. (2002) and has been tested across Northern Australia with factors such as cultivars, sowing date, irrigation, and soil type.

More information on the modelling including inputs, calibration, and evaluation can be found in Hampf et al. (in preparation a, b).

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