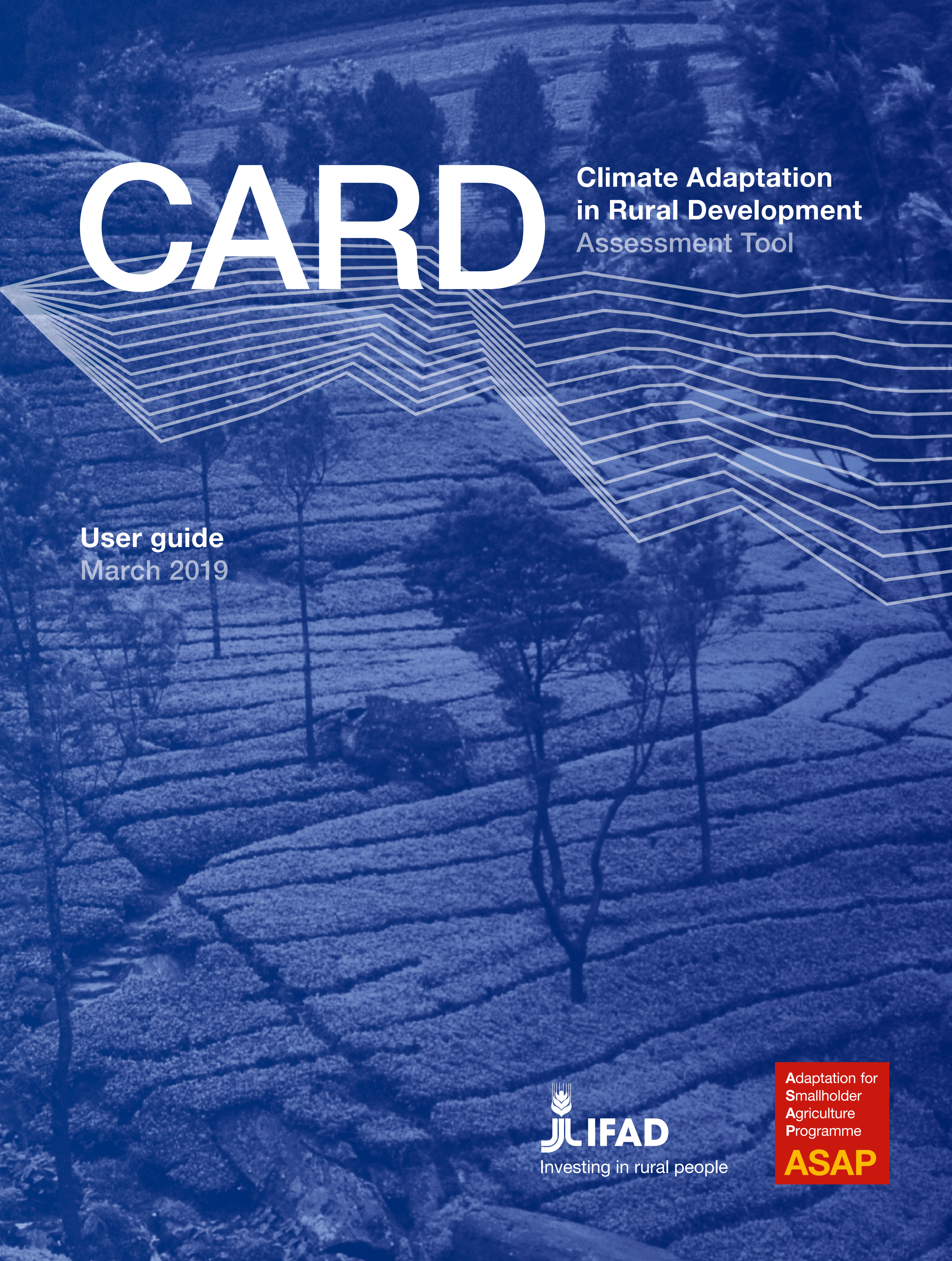

CARD

Climate Adaptation in Rural Development
Assessment Tool

User guide
March 2019

IFAD
Investing in rural people

Adaptation for **S**mallholder **A**griculture **P**rogramme
ASAP

The Climate Adaptation in Rural Development (CARD) assessment tool enables easy access to peer-reviewed modelling results for crop yields under climate change. It has been developed by the West and Central Africa Division of the International Fund for Agricultural Development (IFAD) with funding from Phase II of the Adaptation for Smallholder Agriculture Programme (ASAP2).

The CARD tool's first iteration focuses on Africa according to the following regional division consistent with IFAD's operational segmentation:

- East and Southern Africa
- North Africa
- West and Central Africa

The present manual describes how to use the tool, and presents its comprehensive data selection and sources.

For more information:
CARD team – card.at@ifad.org

Credits
CARD was conceptualized and developed by Florent Baarsch and Amath Pathe Sene (West and Central Africa Division) of the International Fund for Agricultural Development (IFAD). Dr. Anselm Schultes and Philipp Block from Fintu Data Science GmbH implemented the data processing and programmed the tool. Dr. Katharina Waha of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) was a scientific adviser to the project. We thank the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) team for their support in using the ISIMIP simulation data.

1 Why this tool?

Temperature and precipitation are essential input factors to crop growth. With climate change increasingly disturbing their patterns, agricultural production is projected to be more and more affected. Due to its reliance on temperature and precipitation, particularly in rainfed agricultural systems, agriculture is often presented as the sector that is most vulnerable to climate change.

To effectively reduce this vulnerability and ensure food security and rural households' livelihoods, adaptation to climate change is required. In a development and economic perspective, it is essential that the benefits associated with implementing adaptive technologies and practices outweigh the costs. However, assessing the impacts of climate variability and change on crop yields is a complex exercise, largely dependent on the assumptions used, and the availability of historical agricultural and climatic data.

The Climate Adaptation in Rural Development (CARD) assessment tool aims to support the quantitative integration of climate-related risks in agricultural project design, including economic and financial analyses and country strategies led by international and domestic actors. It provides valuable intelligence for investments, food security studies and sustainable development policies, helping foster evidence-based policy dialogues on the issue of agriculture and climate change.

2 How to use the tool

The CARD tool has been implemented through workbooks in Microsoft Excel software. To keep file size to a minimum, the tool will be created for each region. Currently, three African regions are available (East and Southern Africa, North Africa and West and Central Africa). The latest version of the tool can be downloaded [ifad.org/CARD].

Starting the tool

To use the CARD tool, access to **Microsoft Excel 2010 or a later version** is required. Double-click the file downloaded from the website (which should end in **.xlsb**) or use **File → Open** in Microsoft Excel to load the file.

The CARD tool contains three worksheets:

- **Crop yield data:** This worksheet contains the query options, in which you can select: a country; a region or an agroecological zone within that country; irrigation setting; risk setting; and timespan. It also contains a mini-map showing the agroecological (A.E.) zones for the selected country. For the selected query options, it contains relative changes in crop yields under climate change – as both a chart and a table.
- **Country map:** This worksheet contains a larger map of the selected country with its agroecological zones.
- **About:** This worksheet contains general information about the tool as well as basic information about the query options.

Crop yield data worksheet

The **Crop yield data worksheet** (FIGURE 1) is the main part of the tool. In it, you can select the query options and view the corresponding projections for relative changes in crop yields under climate change. The following query options are available:

- Country
- Region/A.E.-Zone
- Irrigation
- Risk setting
- First year
- Last year
- Impact calculation

The following sections give a brief explanation of the individual query options.

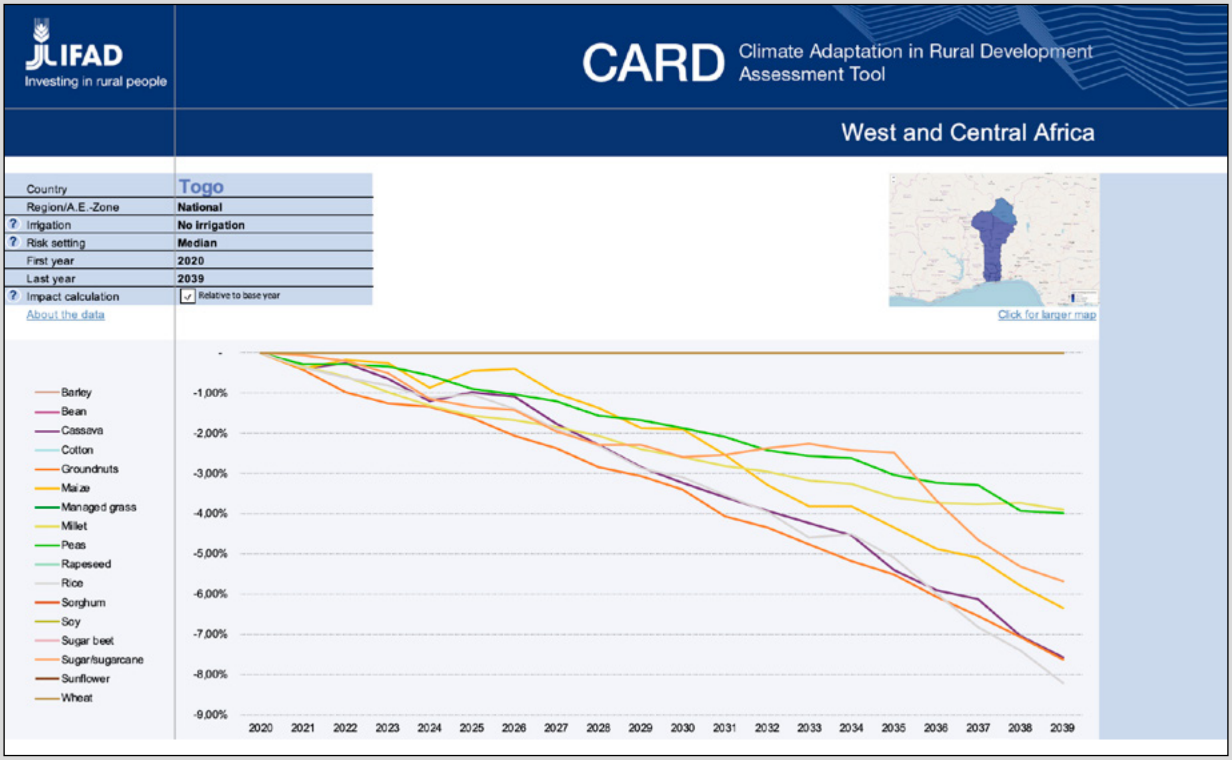

FIGURE 1 **CARD crop yield data worksheet**

Country

This is the first and most important filter option as the following queries are defined by the selected country.

The CARD tool covers almost all African countries.[1] Note that the tool is split in three editions (East and Southern Africa; North Africa, West and Central Africa) to reduce file size. If you cannot find the country you are looking for, consult the CARD website to find the right edition of the tool.

1 The CARD tool considers 54 African countries in total. The simulation data used do not have sufficient geographical resolution to provide projections for: Comoros, Mauritius, Sao Tome and Principe, and Seychelles.

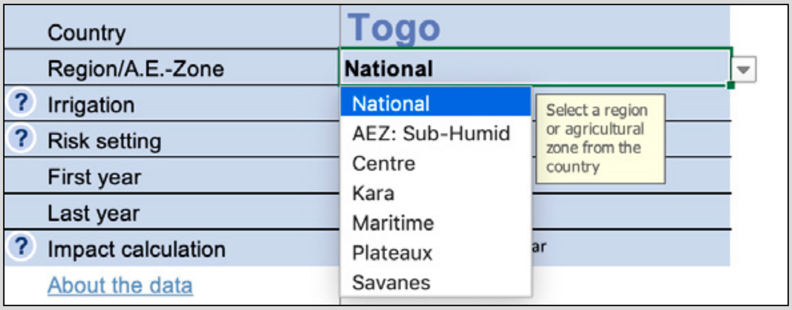

FIGURE 2 **Selection of regions and agroecological zones in CARD**

Region/A.E.-Zone

After selecting a country, you can open the second filter line (Region/A.E.-Zone, FIGURE 2) to select one of the following options:

- **national** for statistics on country level;
- an **agroecological zone** for statistics for the area of the selected country that lies in the selected agroecological zone;
- an **administrative region** inside the country (GADM Level 1).

Only agroecological zones intersecting the selected country and regions of the country can be selected.

Note that if you change the country after selecting an administrative region or A.E.-Zone not present in the selected country, the **Region/A.E.-Zone** selection will be highlighted in red.

Irrigation

The CARD tool contains scenarios assuming either no irrigation or full irrigation. No irrigation means that crop production is rainfed only, while full irrigation means that crops are fully irrigated to the extent that water is available. Please note that for some crops in some of the regions and A.E-Zones, crop production can only be achieved under irrigation. This is particularly the case for arid zones. For these crop-region combinations, the crop yield predictions therefore contain “NA” (short for “not available”) values[2] when “no irrigation” is selected.

The detailed assumptions concerning full irrigation differ by the underlying models used in the CARD tool – for details, please see the model description in Rosenzweig et al. (2013a).

2 There are also other reasons for data to be shown as “NA”; please see Section 4 for an identification of all possible reasons.

Risk setting

The CARD tool allows a choice between three risk settings, which impacts the way the underlying crop-climate models are analysed:

- **Median:** This setting reflects a “best guess” of the uncertainties reflected in the models. The models are aggregated using the median.
- **Pessimistic:** This setting reflects a pessimistic consideration of the uncertainties reflected in the models. The models are aggregated using the 10^{th} percentile of all underlying crop yield projections (i.e. close to the model with the largest decline, or smallest increase, in crop yields).
- **Optimistic:** This setting reflects an optimistic consideration of the uncertainties reflected in the models. The models are aggregated using the 90^{th} percentile of all underlying crop yield predictions (i.e. close to the model with the least decline, or largest increase, in crop yields).

A large spread between the projections under the **Optimistic** and **Pessimistic** risk settings signals significant uncertainty in future crop yield projections. However, a small spread does not necessarily imply a small uncertainty in the projections for a crop, as the spread depends not only on the underlying uncertainty, but also on the number of available model runs. In general, most model runs are available for the four major crops: wheat, rice, soybean and maize. Simulations for other crops rely on significantly fewer model runs, and their projections are thus less reliable.

First year and last year

To obtain predictions of climate change impact on crop yields for a specific time range, you can select a **first year** and **last year** in the respectively named query lines for data to be displayed. Note that both **first year** and **last year** must be between 1995 and 2050, and that **first year** must be earlier than **last year**. If **first year** is not set, data starting from 1995 will be displayed. If **last year** is not set, data until 2050 will be displayed.

Impact calculation

When selecting **Relative to base year** impact calculation, all crop yield impacts are calculated relative to the first year selected in the field above – as a consequence, the displayed impact calculation starts at 0 for the **base year**.

Otherwise, crop yield impacts are relative to 1995, the first year included in the tool. The CARD tool uses 1995 as the base year as it is centred in the reference period of 1980-2010 of the underlying crop-climate models. As the simulation data are averaged over 30 years, the value in 1995 thus corresponds to the mean over the reference period. In this setting, the impacts displayed also account for the lack of adaptation of the crops to their current climate compared with the observed climate in the reference period (1980-2010).

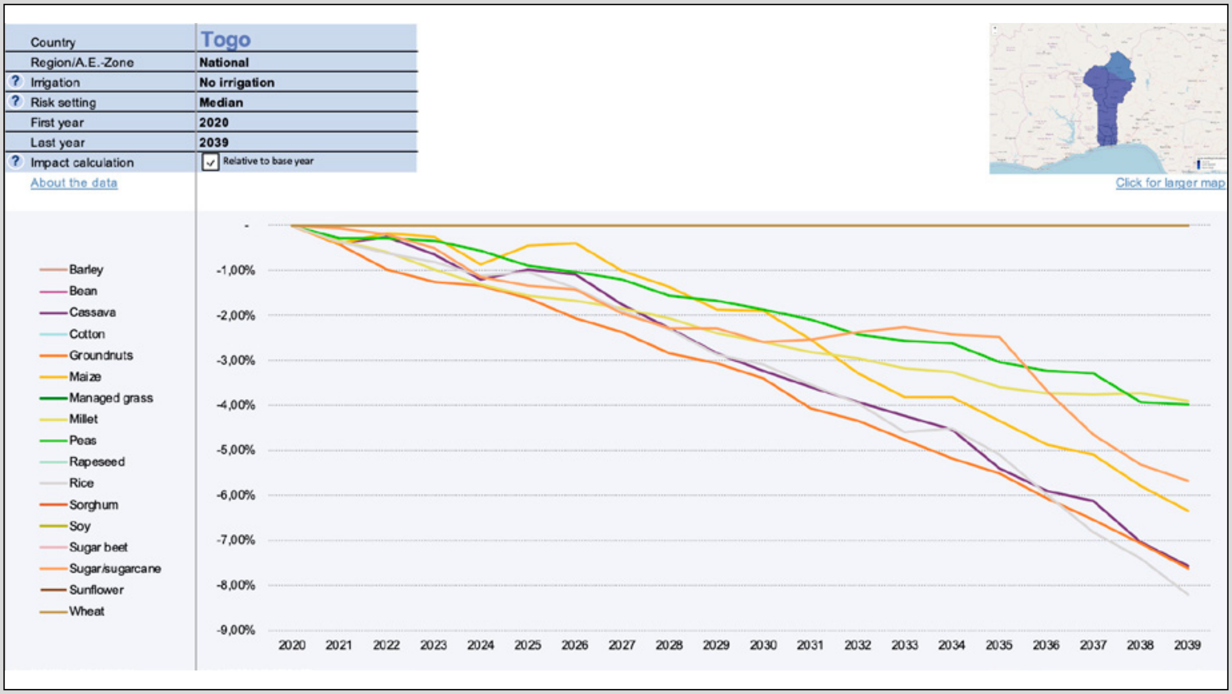

FIGURE 3 **Median change in crop yields without irrigation at the national level in Togo relative to the base year (2020) until 2039**

Example
Consider crop yield impact projections from 2020 to 2039 in Togo on a median risk setting without irrigation (FIGURE 3). When selecting **Relative to base year**, all crop yield impacts are calculated relative to the first year of the selection, i.e. 2020. Therefore, relative impact in 2020 is zero. This is useful if the user has access to crop yield statistics for the first year and wants to calculate the changes over the selected period relative to these observations.

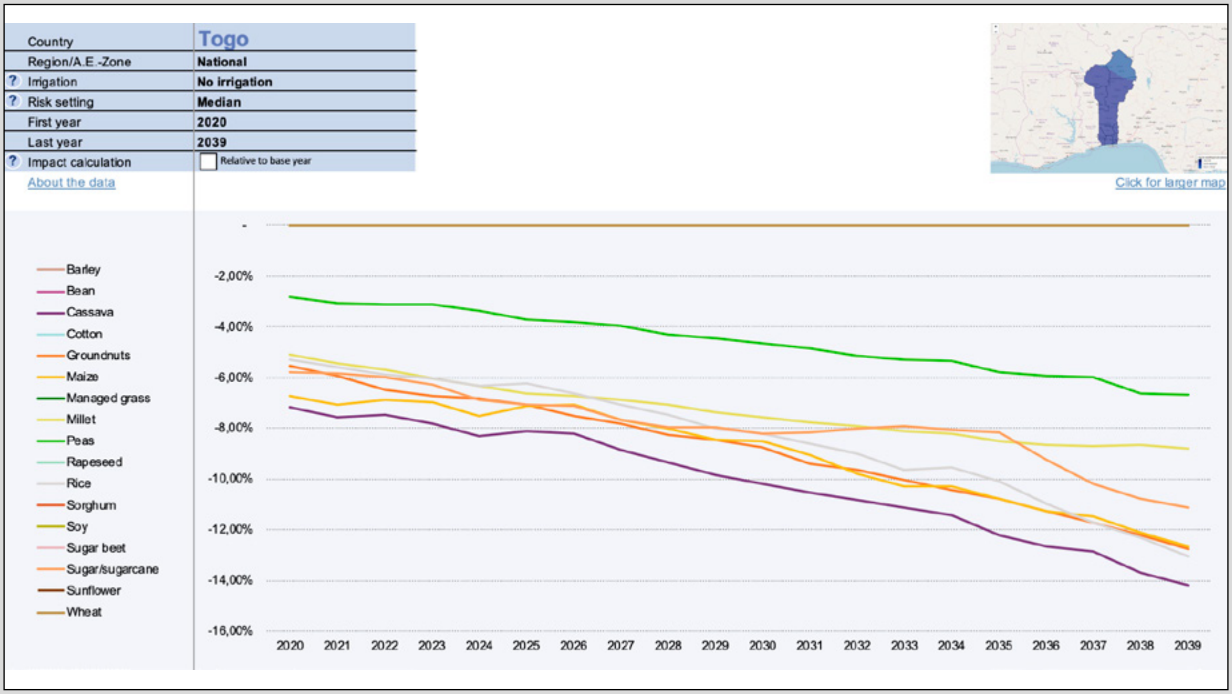

FIGURE 4 **Median change in crop yields without irrigation at the national level in Togo relative to the base 1995 with data presented for 2020-2039 period**

When deselecting **Relative to base year** impact calculation, all crop yields are calculated relative to the base year of the underlying models, 1995. In that case, there will already be a significant impact in 2020, as predicted by the underlying models (FIGURE 4).

3 Key considerations

RCP8.5 scenario

To circumvent the issue of complexity associated with climate models, scenarios and data, the developers of the CARD tool decided to simplify as much as possible the outputs available in the tool. Therefore, only one climate change scenario (Representative Concentration Pathway, RCP), the RCP8.5 scenario, was selected. The RCP8.5 (Riahi et al., 2011) scenario is the scenario from the Intergovernmental Panel on Climate Change projecting the highest concentration in greenhouse gases (GHGs), and hence the highest global warming. Two main reasons explained below underlie the selection of this scenario.

1. Historical emissions are in line with the emissions of the RCP8.5 scenario. As estimated in 2014, global GHG emissions from fossil fuel and the cement sector are consistent with the highest warming scenario (RCP8.5). According to projections from the *Emissions Gap Report 2018* (UNEP, 2018), accounting for the full implementation of the current climate policies would limit global emissions to 60 $GtCO_2eq$ by 2030, while 42 $GtCO_2eq$ would be required to maintain global mean temperature increase below 2°C (FIGURE 5).
2. The difference in global mean temperature increase in the period between nowadays and 2050 (the period used in the CARD tool) is limited. In the period 2031-2050, global mean temperature increase ranges from about 1.2°C in the highest warming scenario to 0.8°C in the lowest warming scenario. Moreover, considering a time frame of agricultural projects of a maximum 20 years (6 years of implementation and 14 years of "capitalization"), the most relevant period is actually 2020 to 2039, during which model median estimates largely overlap (FIGURE 6).

Carbon dioxide fertilization

The carbon dioxide (CO_2) fertilization effect is the process by which crop photosynthetic activity accelerates as a response to the increased concentration of CO_2 in the atmosphere (Allen, Baker and Boote, 1996). However, the ability of smallholder farmers to benefit from this effect is unclear. Indeed, according to Tubiello, Soussana and Howden, 2007 crop yields are expected to increase by 10-20 per cent for C_3 crops (e.g. wheat, rice) and 0-10 per cent for C_4 crops (e.g. maize, millet) if atmospheric CO_2 concentrations rise from 380 ppm to 550-600 ppm, but only if other biotic (like pests) or abiotic (like nutrients) factors do not become limiting (Long et al., 2006). In accordance with Waha et al. 2013 we therefore assume that it is unlikely for CO_2 fertilization to have a strong effect on crop yields at current management intensities in sub-Saharan Africa and the tool will only show crop yield changes without the CO_2 fertilization effect. As a consequence, the projections shown in the CARD tool are without CO_2 fertilization to account for: (i) the

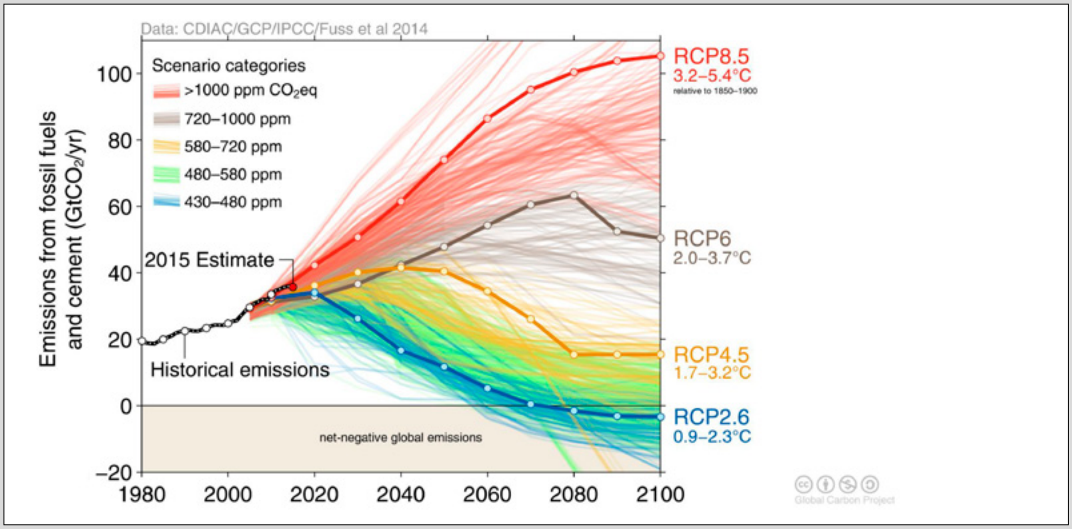

FIGURE 5 **Historical emissions and emissions associated with the RCP2.6 to 8.5 for 1980-2100**
Source: Fuss et al. (2014)

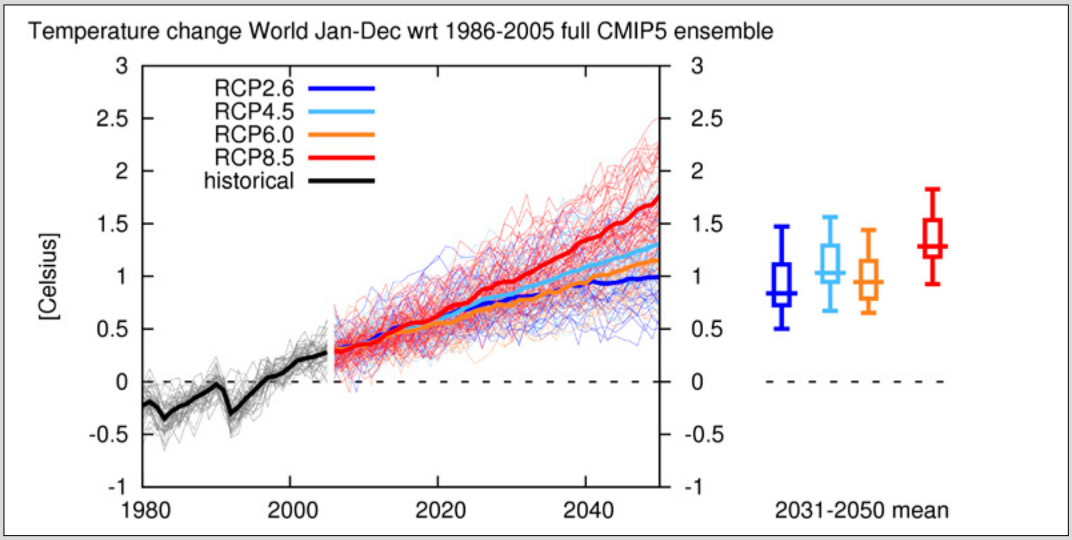

FIGURE 6 **Global mean temperature change between 1980 and 2050 with respect to the 1986-2005 reference period in RCP2.6, 4.5, 6.0 and 8.5** Source: KNMI (2019)

uncertainty associated with this effect in farmer's fields given other limiting factors and for non-cereals; and (ii) the unlikely possibility that smallholder farmers will be able to implement new agricultural management practices enabling them to benefit from the CO_2 fertilization effect.

4 Climate-crop model data

Overview

The crop yield changes under climate change in this tool derive from long-term simulations using global gridded crop-climate models. The CARD tool's set of simulations – a model ensemble – was created by many different scientific groups and coordinated by the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP). This model ensemble, called ISIMIP Fast Track, was released in 2013 and is described in full in Rosenzweig et al. (2013a).

The general idea is to use an ensemble of global gridded crop-climate models, driven by a set of different evolving climate conditions, in order to explore many different possible futures. The different pathways for future crop yields from the model ensemble are then summarized into statistical indicators (e.g. the median) to create robust projections under climate change.

Crop models

Global gridded crop-climate models simulate the biophysical processes related to crop growth in order to capture long-term effects of climate change. The models in the ensemble used here simulate processes until 2100 in grid cells of size 0.5° × 0.5°. The seven global gridded crop-climate models in the ensemble differ somewhat in the degree of processes represented and their management settings (for full details, please see the Supplementary Information of (Rosenzweig, et al., 2013b). Crop processes simulated in at least some of the crop models include: leaf area development, light interception and utilization, yield formation, crop phenology, root distribution responsiveness to water availability at soil depth, water and heat stress, soil–crop–atmosphere water cycle dynamics, evapotranspiration, soil carbon and nitrogen cycling.

The ISIMIP Fast Track focuses on the effect of inputs (such as CO_2, water and nutrients) on long-term yield levels rather than focusing on shocks (pests and diseases are not considered). Major drivers of crop growth, which are included by all crop models, are temperature and water availability.

Climate models and scenarios

Future climate conditions, which enter the crop models as drivers, are based on climate model runs coordinated by the Coupled Model Intercomparison Project Phase 5 (CMIP5). The five underlying climate models used here are general circulation models that simulate future climate conditions under different scenarios of future GHG emissions. This tool considers RCP8.5 as the only future climate scenario – see Section 3 for details on the climate change scenario selection.

Climate simulation outputs serve as input for the global gridded crop models (at daily resolution). One caveat is that the current general circulation models do not fully resolve all short-term weather extremes (e.g. monsoon dynamics), some of which may be relevant for crop impacts.

Statistical summaries

A sequence of transformations produces the statistical summaries included in the Excel tool from the raw ISIMIP model simulations.

Gridded crop production is calculated as a product of the simulated crop yields and the harvested areas for each crop in each grid cell. The "annual harvested area grids for 26 irrigated and rainfed crops" data of the MIRCA2000 dataset (Portmann, Siebert and Döll, 2010) is used for estimates of harvested areas, separately for rainfed and irrigated areas. Rainfed harvested areas are used to aggregate crop yields of the **no irrigation** simulations, whereas areas irrigated according to MIRCA2000 are used to aggregate the **full irrigation** scenarios.

All relevant geographies (national, regional and agroecological zones)[3] for African countries derive as geographical shapes. These shapes are used to aggregate the production data, which come as a 0.5° × 0.5° grid, to each geography. If a grid cell is not fully contained in a geography, its production value in the aggregation is weighted by the grid cell's share that falls into this geography. Grid cells for which there are no simulated crop yields – for example, because of mountainous terrain or only water in that cell – are set to zero in the weighted sum.

This gives a measure of total crop production as a time series for each combination of geography, climate model run, crop model run, and scenario. Geographies that intersect with fewer than five grid cells are discarded, as for such small geographies the internal variability of the underlying climate and crop models results would excessively influence the results.

In order to single out the effect of long-term climate changes from the simulations of yearly yields, the 30-year moving average is calculated for every time series. Crop models report different measures of yields, e.g. potential or actual yields (Rosenzweig et al., 2013a, 2013b). To be able to compare between models, each time series is normalized to the reference period (1980-2010) by dividing by the 1995 value (after averaging over 30 years).

For each combination of crop type, year, geography, and irrigation scenario, statistical summaries are calculated over the crop and climate models separately (median, 10th and 90th percentile).

3 Based on the GADM (https://www.gadm.org) and Harvestchoice (https://harvestchoice.org/data/aez8_clas) datasets.

Combinations are discarded if they meet one of the following criteria:

- "No irrigation" scenarios in arid agroecological zones. Reason: No relevant rainfed cropping expected in these areas.
- The production value (according to the model mean in 2010) is below 500 tons per year. Reason: The production is too limited to be relevant to the end-user.
- The standard deviation (calculated across crop-climate model runs), a measure for model disagreement, is larger than 0.1. This may be caused by models showing extremely different trends, and/or few model runs. Reason: Simulation results are deemed too unreliable or uncertain to present to the end-user.

5 Robustness checks

Robustness checks in two areas were conducted: (i) verification of the processing of the simulation data itself; and (ii) verification of the Excel-based tool.

The statistical summaries of the simulation data are verified by comparing against the published model ensemble, as found for example in Figure 3 of Rosenzweig et al. (2013b). While there is no exact correspondence of the scenario choices, the overall trends in the yield changes match.

Meticulous measures are taken to ensure that the correct model results are displayed in the Excel-based tool. The formulas of the underlying query mechanism have been verified independently by two specialists, both in terms of query logic as well as actual resulting data using various spot checks. A standardized and fault-tolerant data-loading process has been designed and documented to update the Excel-based tool with new data. Each step of the process includes consistency checks with the underlying data as well as functional checks of the tool logic.

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