FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Climate-smart coffee in Uganda

Summary

Uganda is Africa's second largest coffee producer. Its 1.7 million smallholder coffee households represent 10% of global coffee farms. The annual production of 3-4million bags coffee accounts for 18% of the country's annual exports.

About 77% of annual production is Robusta coffee produced in Central Uganda. Arabica is produced on the borders with Rwanda and Kenya. Most production is on small plots (0.25ha) that are intercropped with banana and other food crops.

Coffee production areas in Uganda have become drier and hotter over the past three decades. Annual temperatures have risen across the country, potential evapotranspiration increased, and the distribution of precipitation has become more variable.

Global climate models project annual mean temperature to increase by 1.7°C-1.8°C until mid-century. In line with the current trend, the increase is projected to be higher in the South-West, than in the East of Uganda. Projected increases in total annual precipitation are substantial and range from +6.8 % (South West) to +11.5% (South-East) averaged over all projections.

The contradiction that East Africa recently experienced a series of devastating droughts, whereas the majority of climate models predict increasing rainfall for the coming decades has been termed the East African climate paradox. Whether or not the future climate in the region will indeed become wetter or not should be considered an open question.

To support effective adaptation, we developed a gradient of climate change impacts for coffee production. The gradient is a coffee specific evaluation of the projected climatic changes described above. The impact gradient shows that, although most of Ugandan coffee production can be sustained, the majority of the suitable area is in need of substantial adaptation efforts.

Local production systems are maladapted to future conditions and without adaptation, coffee in Uganda would likely become uneconomical with climate change in most regions. However, globally coffee production systems have been adapted to a wider range of climate conditions than currently observed in the country, suggesting that with global technology transfer, especially of germplasm, Uganda may remain suitable for coffee production.

Because of the high climate uncertainty for Uganda, we recommend a site-specific stepwise CSC pathway for adaptation. Local experts developed a sequence of farm level practices, in which each step requires additional effort. This aims to make the adoption of these practices feasible for resource-constrained smallholders.

To be successful, planning and implementation of interventions for climate-smart practices in Uganda need to consider the system in which coffee producers make their decisions. Informal land tenure, gender relationships, and poor market access are disincentives for CSC adoption. Enabling interventions facilitate and support the adoption of climate-smart technologies and practices by providing services and financing to farmers.

Active efforts to scale out climate-smart practices are a priority to secure long-term sustainability of the coffee sector. Because coffee production is an investment of several decades and many CSA practices have a long lead-time, adaptive action needs to be taken immediately with forward-looking thinking. A multi-stakeholder approach will be required as no single technology or scaling pathway may account for the diversity of decision environments of the actors involved.

The climate-smart agriculture (CSA) concept reflects an ambition to improve the integration of agriculture development and climate responsiveness. It aims to achieve food security and broader development goals under a changing climate and increasing food demand. CSA initiatives sustainably increase productivity, enhance resilience, and reduce/remove greenhouse gases (GHGs). While the concept is new, and still evolving, many of the practices that make up CSA already exist worldwide and are used by farmers to cope with various production risks. Mainstreaming Climate Smart Coffee (CSC) requires critical stocktaking of the sector fundamentals, already evident and projected climatic developments relevant to coffee production and promising practices for the future, and of institutional and financial enablers for CSC adoption. This CSC profile provides a snapshot of a developing baseline created to initiate discussion, both within countries and globally, about entry points for investing in CSC at scale.

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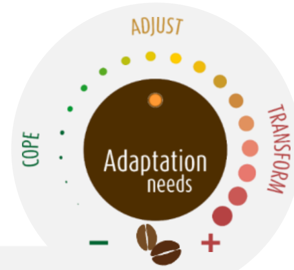
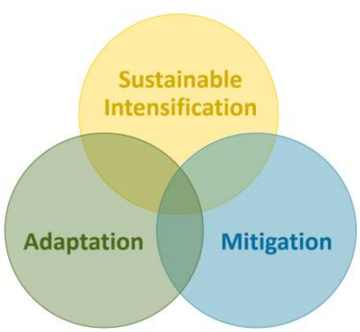


Climate smart coffee

Climate smart coffee (CSC) production sustainably increases productivity, enhances resilience to climate risk, and reduces or removes greenhouse gas emissions (GHGs). While the concept is new, and still evolving, many of the interventions that make up CSC already exist worldwide and are used by farmers to cope with various production risks. Interventions can take place at different technological, organizational, institutional and political levels.

Adaptation to climate change is often understood as a change of production practices at the farm level. Because of the high uncertainty in the future changes of the climate in Uganda, we recommend to use site-specific Stepwise Climate-smart Investment Pathways. Local experts developed the suggested sequence of farm level practices, in which each step requires additional effort. This aims to make adoption of these practices feasible for resource-constrained smallholders.

With an increasing degree of climate impacts, the importance of systems approaches to adaptation and the enabling environment increases. Practice focused adaptation reaches a limit when the climate changes to a degree that makes alternative systems more attractive. In this case, a change of the livelihood strategy may be necessary. Value chain inclusive systems approach to adaptation, therefore, include a wider range of actors or crops to manage risk from coffee. The chain itself may be made risk-proof or more efficient, for example at processing and transport stages, or where farmers and exporters choose to diversify into alternative crops. Such systemic or transformational adaptation may require changes to the framework conditions or enabling environment for CSC. This enabling environment includes policies, institutional arrangements, stakeholder involvement and gender considerations, infrastructure, credit, insurance schemes, as well as access to weather information and advisory services.

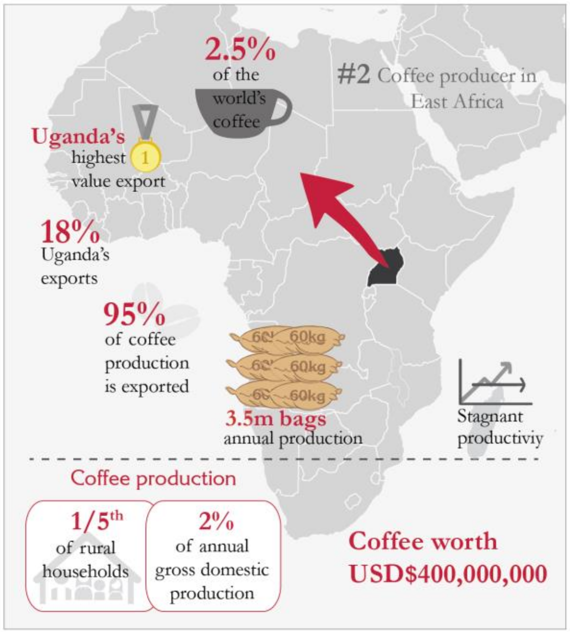


The effective design of such interventions requires an understanding of the climatic changes that are observable in historical weather data, currently perceived by farmers and projected by global climate models. This brief therefore discusses these data for Uganda and the potential pathways to mainstream climate-smart interventions in the country.

Three degrees of adaptation **effort**

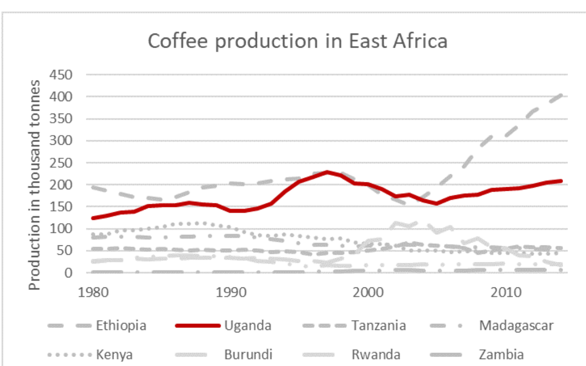
- **Incremental** adaptation where climate is most likely to remain suitable and adaption will be achieved by a change of practices and ideally improved strategies and enablers
- **Systemic** adaptation where climate is most likely to remain suitable but with substantial stress, adaptation will be achieved through a comprehensive change of practices, but also requires a change of strategy and adequate enablers
- **Transformational** adaptation where climate is likely to make coffee production unfeasible, this will require a focus on a change of strategy and adequate enablers as practices alone may be uneconomical

National context



Economic relevance of coffee

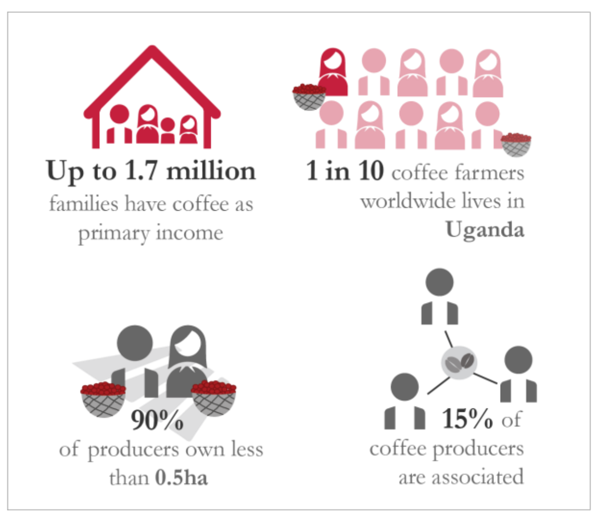
At 3.5 million 60kg bags, Uganda is the 10th largest coffee producer in the world and the second largest in East Africa. Coffee production in East Africa has declined or stagnated for more than 40 years, while other regions significantly increased output. The notable exception is Ethiopia, which doubled its output in less than two decades, whereas Uganda saw slower growth. In the late '90s productivity was significantly higher for about a decade, but this has reverted back to the levels of the 1980s. Increases in production (~ 1.5%/year) during the last two decades come from an expansion of area [1]. For the last two seasons a substantial increase in production to 4.5million bags was reported [2].



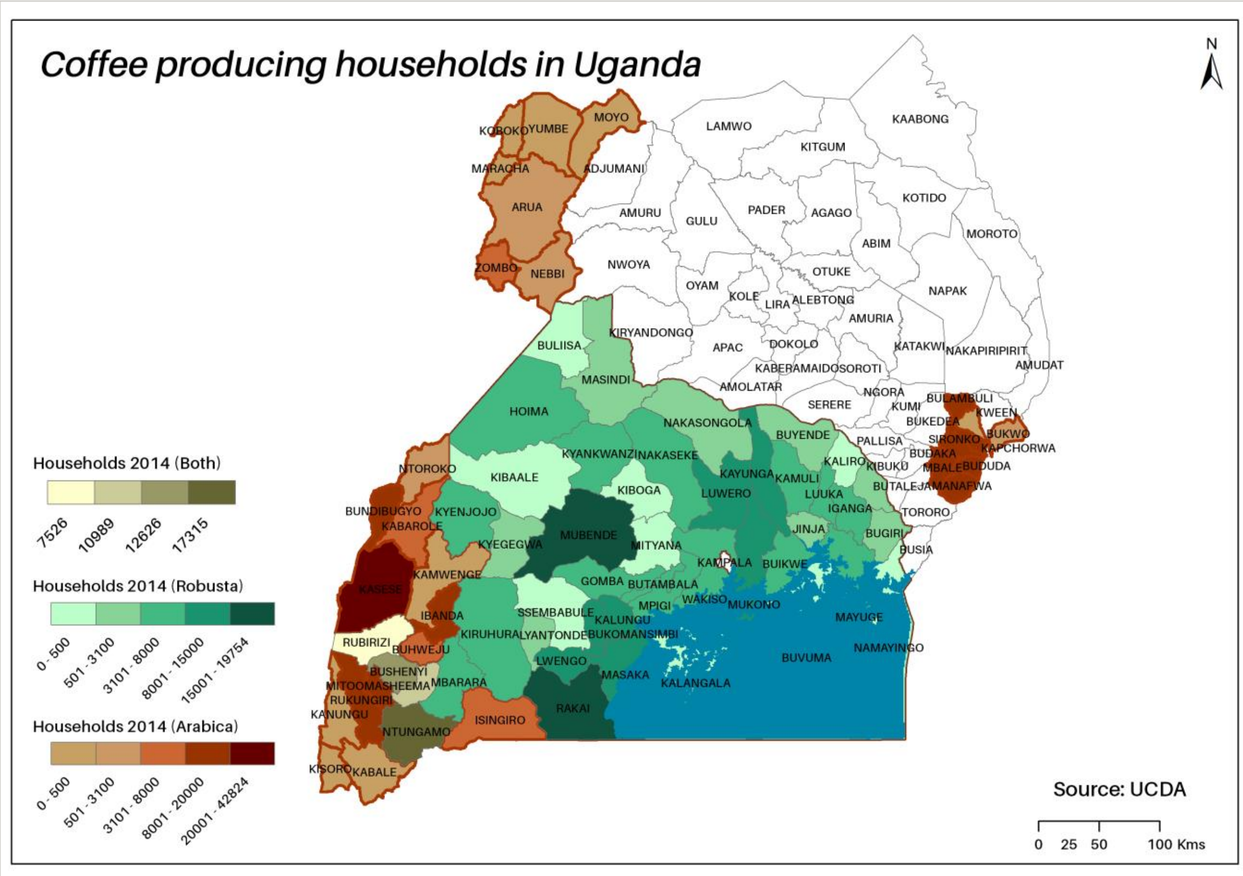
Coffee is Uganda's highest value export, a position it has held for decades but which was recently challenged by gold exports [3]. The share of coffee of total foreign exchange earnings is between 15-18% annually. Annually, Uganda exports 95% of the total coffee production for earnings between 350-400 million USD. Traditionally, the European Union is the largest importer of Ugandan coffee, followed by Sudan. Export volumes have remained constant, but the share of EU imports of Ugandan coffee has declined from 75% to 60% in recent years as the importance of less traditional importers, such as Tunisia and India, has increased.

Coffee production accounts for about 5% of rural gross domestic product (GDP) and contributes 1.2% to the national GDP. Coffee processing accounts for another 0.8% of GDP. These shares have been roughly constant over the last decade despite the growth of the industrial sector because of the constant increase in coffee output.

The importance of the coffee sector as a key driver of rural economic activity and income source cannot be understated. Every tenth coffee farm globally is located in Uganda. Between 1.2 and 1.7 million families in Uganda produce coffee: this is every 4th rural household, or every 5th household nationwide and in Uganda approximately every 4th or 6th person lives in a coffee family. In addition, coffee provides a livelihood for an unknown number of workers and traders.



Coffee and land use



Uganda has the third highest deforestation rate worldwide [4] and the conversion to agricultural land has been a major driver of this development. Since 1990 about 55% of natural forests have been eliminated and converted to other land uses. Forests used to cover 20% of the country in 1990, agricultural expansion to 40% of the land, among other factors, has led to forests covering just 9% in 2015 [5]. Although the role of coffee in the transformation of the Ugandan landscape is hard to quantify, it is reasonable to argue that coffee plays an integral part of the rural landscape. In fact, the area cultivated with coffee expanded by 50% since 1990, and a fifth of agricultural households produce coffee on about 5% of total agricultural land. Because of the widespread loss of tree cover, coffee agroforestry could play a positive role for sustainable land use, especially if area expansion can be limited to land previously used for field crops or livestock.

Coffee production segments

Uganda produces both Robusta (~77%) and Arabica (~23%) coffee. Coffee is produced on small plots, often intercropped with banana (Matoke) or other food crops, but shaded or full-sun monoculture is not uncommon. Estimates about the prevalence of different agroforestry systems at country scale do not exist. Shade composition is usually of low species richness because of the overexploitation of agroforests by farmers in lieu of access to natural forest [6,7]. Few farmers engage in replanting and, instead rely on natural regeneration, yet the promotion of shade trees for ecosystem services is recommended [6].

From 2007/08 until 2015/16 the share of certified coffee of total exports was 1.2% of the Robustas and 5% of the Arabicas. At export, only UTZ certified or Certified Organic is reported. Quantities of other certifications such as Fair Trade or Rainforest Alliance are either not stated or not exported [2].

Some sources claim that up to 20% of coffee in Uganda is certified but not sold as such [8].

Uganda employs an elaborate quality grading system [9]. Certificates for the various grades are issued by the UCDA. Coffees are differentiated by species, process, bean size and other quality attributed plus certification and origin. As a result, UCDA statistics report 15 Robusta grades and 35 Arabica grades. However, the most important grades, in terms of export volume, are screen size grades 12, 15 and 18 for Robusta, and for Arabica it is Natural Arabica ("Drugar" – Dry Ugandan Arabica) [2].

Productivity and poverty indicators

Coffee in Uganda is produced on diversified farms, alongside multiple other crops, on extremely small plots with very low input use. The average coffee plot size is 0.23ha. 90% of farmers own plots of less than 0.5ha, representing 60% of the total area. The largest 10% of producers occupy 40% of the coffee area in plots of approximately 1.0 ha. Only 25% of households used hired labor [10].

Most farmers are highly diversified and cultivate three or more crops on their farmland. Some difference exists between extreme smallholders and the top 10% of coffee households. The lowest strata produce more crops on less land than the group with more coffee area.

Input use is very low in Uganda. Across all households, only 3.5% of coffee households use inorganic fertilizers, and 9% apply pesticides. Household size has a significant impact on these numbers with the largest 10% of households being three times as likely to use inputs: 18% use pesticides versus only 5% of the lower 90% (5% vs. 1.5% for fertilizer use) [10].

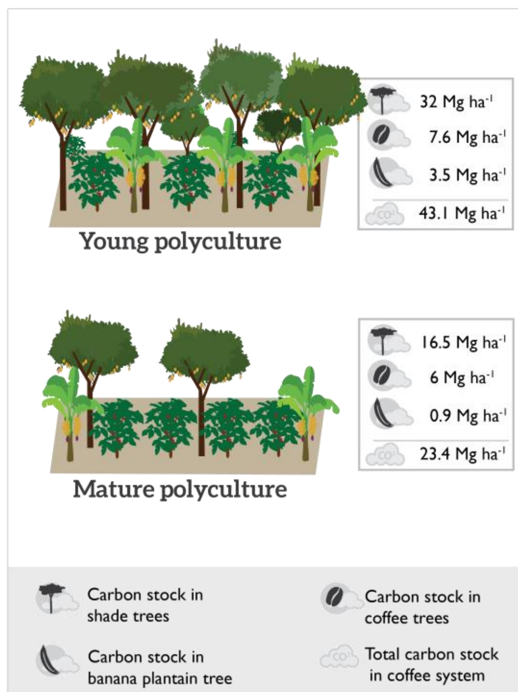
Inputs are paid almost entirely in cash (98%) immediately at purchase (92%) and only 8% on credit. This is despite the observation that 23% of households report that they would have access to credit or are members of credits and savings unions. Village savings and loan associations have been used by 27% of farmers [11].

For ~70% of coffee households farming is the main source of income. For about 5%, remittances are the main source of income and a minor source for 25%. Thirty percent of households at times don't have enough cash for food but just 14% report that their income is below the living minimum. Average per capita daily income was estimated to be 0.85USD which is about half of the international poverty line. Despite the fact, that very few coffee households have a per capita income above the poverty line, they still have a 10% higher income than non-coffee rural households in Uganda.

Coffee greenhouse gas emissions

Coffee production is vulnerable to progressive climate change but at the same time contributes by emitting greenhouse gasses. Emissions can be assessed using tools such as the Cool Farm Tool [12].

The most important aspects of the climate impact of coffee production are the standing carbon stocks in the production systems and the product carbon footprint, which measures the GHG emissions per unit weight of coffee produced. The data presented here spans across the main Robusta producing systems in Uganda comparing low shade and high shade density systems. For Arabica systems no data was available.



High Shaded Robusta Systems have a higher carbon stock on average (43 Mg ha^{-1}). This is composed of carbon stock of the shade trees (75%), coffee trees (18%) and banana and plantain shrubs (8%). The carbon stock of Low Shaded Systems is 46% lower (23.4 Mg ha^{-1}), although shade trees still make up the majority of the carbon stock (70%), the contribution of coffee trees (26%) is higher and that of banana and plantain trees (4%) is lower. These differences are due to higher planting densities of shade trees and banana stems in High Shaded Robusta systems compared to those in Low Shaded System (being 117 and 1827, respectively versus 79 and 468, respectively). Across Robusta systems, *Mangifera indica* (mango), *Albizia coriaria*, *Artocarpus heterophyllus* (jackfruit), and *Ficus natalensis* are the four most common species in terms of tree count abundance and carbon stocks (account for more 75% - 82% of total carbon stock).

Uganda Robusta coffee systems are low input systems compared to for example Vietnamese Robusta coffee systems. In the former systems, inorganic and organic fertilizer use is less than 10 kg ha^{-1} and around 160 kg ha^{-1}, respectively. Therefore, the product carbon footprint is low (0.72 kg CO_2-e kg^{-1} green bean), about five times lower compared to that of the latter systems. The main sources of GHG emissions stem from soils (92%), followed by emissions from crop residues (7%). Inorganic fertilizer accounts of 1% of the emissions and organic fertilizer and transport both less than 1%.

Challenges for coffee production

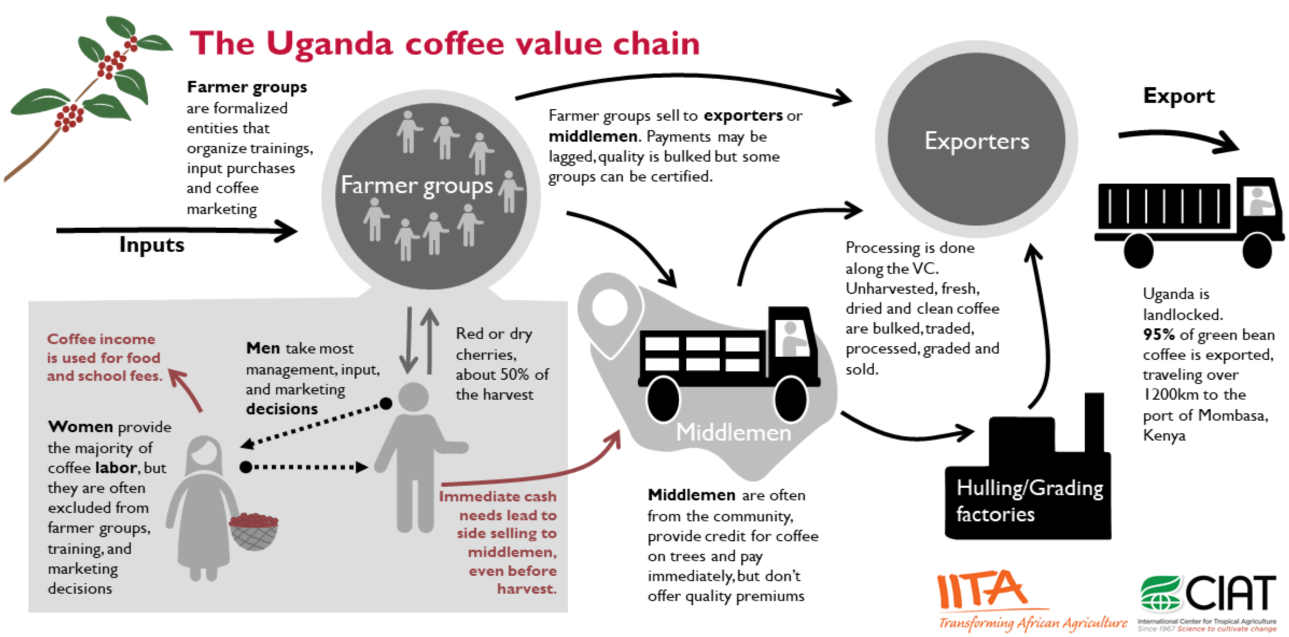
Coffee production in Uganda is extremely fragmented, organizational levels and input use are low and households are extremely poor [9]. Access to training, information, and quality inputs is difficult. Value chains don't incentivize sustainable practices and landscapes are degraded. Institutional capacity to respond to challenges is low and regulations are often not enforced despite the political importance of coffee [13].

Land tenure and land use changes are a threat to the stability of production. 80% of agricultural land is under customary tenure that is undocumented [14]. In this potentially insecure situation, producers often don't have incentives for sustainable land management. The fast-growing population aggravates the situation as in traditional inheritance rules, the land is fragmented into ever-smaller plots [13]. Weak property rights and land tenure have facilitated the rise in land-grabbing[15]. Growing cities, oil and gold production, and expansion of estate crops can result in land use change in which smallholder coffee producers are at risk of being driven off their land without legal means or ways to benefit from increasing land prices.

Women are discriminated against in having access to and inheriting land[15]. Such gender gaps are likely to contribute to inefficient and unsustainable household farming. Perceptions of risks and adaptation strategies differ across gender. All of the key elements of adoption of CSA practices have a gender dimension in Uganda: decision-making power, technical capacity, and access to information and physical and financial resources.

Women in Uganda are more likely to be illiterate than men, leave school earlier [16], receive a lower share of the coffee income and have less decision making power [17], while often carrying an equal or larger share of the labor and management burden [18].

The coffee value chain connects the 1.7mio farmers that each produce a few bags with about 45



exporting companies [2]. Following market liberalization, many cooperatives went defunct due to corruption and uncertain and delayed payments to farmers. Instead, numerous intermediaries entered the market and in recent decades farmer groups evolved as a means for collective input purchases, processing, and marketing. Farmer groups are registered entities with a diverse organizational structure and purpose. The high competition of intermediaries results in a high price transmission to farmers and timely payments at sale [19]. Intermediaries often originate from within the community and farmers often sell them cherries before harvest because of immediate cash needs, foregoing farmer groups [20]. The latter may negotiate better prices, receive premiums or add value through processing and transport activities, but payments may be delayed.

The diversity of stakeholders of the value chain often does not provide incentives for sustainable practices. Intermediaries and farmer groups bulk coffee from several producers so that higher quality or sustainable practices do not receive premiums. The ability of farmer groups to improve commercialization depends largely on their composition, i.e. common interests of their members [20]. Nevertheless, farmer groups positively contribute to their member's capacities, risk reduction and access to finance [21]. Last, because Uganda is landlocked, coffee has to be exported over 1200km of road to Mombasa, Kenya. The cost and time of this limits Uganda's potential to export non-commodity grade coffee or roasted/instant coffee [19].

Pests and Diseases

Two main pests and diseases affect Robusta production in Uganda: Coffee Wilt Disease *(CWD, Fusarium xylarioides)* and Black Coffee Twig Borer *(BCTB, Xylosandrus compactus*). For Arabica the African Coffee White Stem Borer (CWSB, *Monochamus leuconotus*), Coffee Berry Disease (CBD, *Colletotrichum kahawae),* Coffee leaf rust (CLR, *Hemileia vastatrix*) and the Coffee Berry Borer (CBB, *Hypothenemus hampei*) are of increasing concern.

CWD is a fungal disease that blocks the vascular system of the plant, causing the plant to wilt and eventually die [22]. The disease was first detected in Uganda in 1993; by the end of 2000 it had spread to all Robusta zones of the country. Ugandan Robusta production reached a peak in 1996 and then fell steadily up to 2005, when it attained only 42% of peak production. It is very likely that most or all of the fall in Robusta was due to CWD.

BCTB is a beetle that has been of serious concern since a 2007 outbreak. A 2012 survey reported that it had affected some 70% of coffee holdings, causing losses of about 8.5% of national Robusta production [23]. The phytosanitary control requires large investments in labor. Chemical control is ineffective because BCTB remains concealed inside coffee twigs. Some authors are discussing the possibility that global warming may decrease BCTB prevalence, although precipitation variability might also increase prevalence [24].

WCSB is a beetle that ring barks the plants, affecting the vascular transport system so that heavily-affected young trees may die. Because the pest develops inside the trunk, it is difficult to control, and few economically-effective chemicals are available. Up to 80% of coffee farms in eastern and southern Africa were infested and suffered crop damage [25].

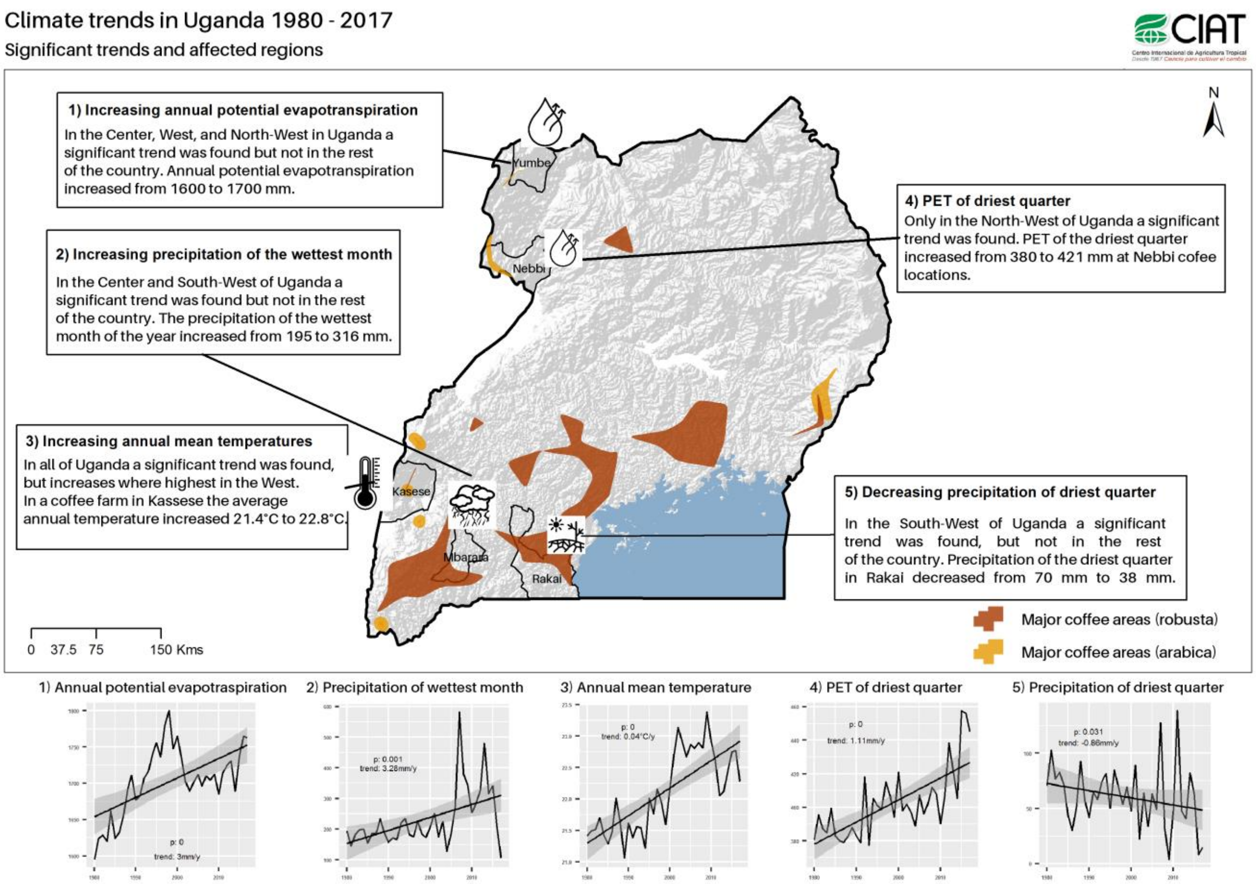
CBD is a fungal disease infecting Arabica flowers, fruits, leaves, and even maturing bark. The economic impact results from a massive drop of infected green berries. Yield losses up to 80% have been reported [26].

CLR has caused tremendous damage to the Arabica coffee sector of the Americas over the past few years. In Uganda, the impact of CLR became apparent in the 1940s when areas of land typically producing Arabica, had to be replaced with Robusta [25]. Recently, this disease is of increasing concern.

Another concern is the coffee berry borer (CBB) which plants its eggs in the berries. The highest incidence occurs at the onset of the wet season and management is mostly manual. The CBB has been shown to benefit from higher temperatures through higher reproduction rates and is increasingly a problem at higher altitudes [27].

Coffee and climate change

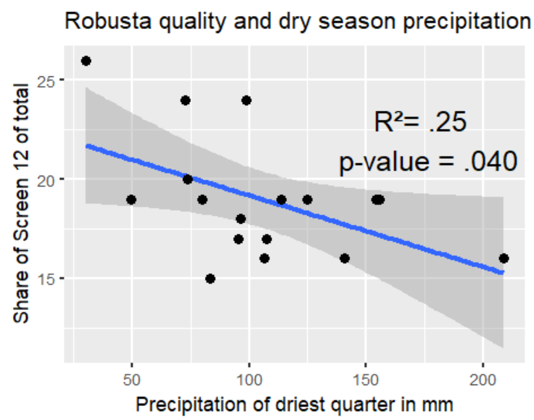
Climate data matches the perceptions of coffee experts and producers reporting changes in climate and an increase in adverse climatic events such as irregular rainfall, increasing temperature range, drought, extreme rainfall, and high temperatures. These trends are said to be of high or very high impact on coffee production by changing pests, diseases and weeds, soil erosion and landslides, and irregular flowering. Recent drought events were perceived as extreme and estimated to have caused yield losses of 50%. In Uganda, droughts are discussed to have caused deterioration of bean quality. In this section, we will first describe climatic changes that we could find in observed climate data from 1980 until 2017. Next, we will report changes that were projected by global climate models in a climate change scenario of intermediate severity.



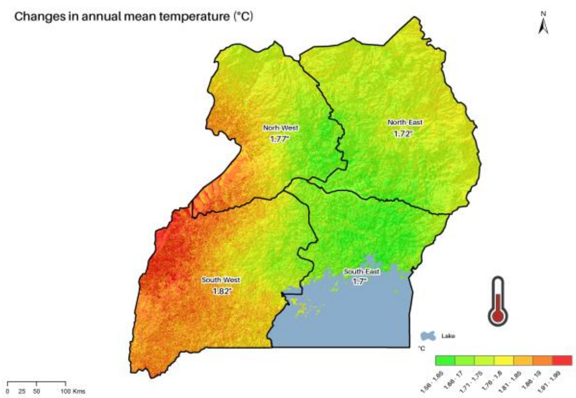
Observed climate risk and trends

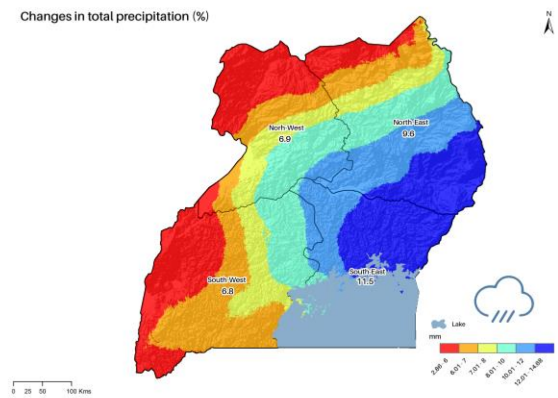
Coffee production areas in Uganda have become drier and hotter over the past three decades. Annual temperatures have risen across the country, potential evapotranspiration increased, and the distribution of precipitation has become more variable. The extent of these developments varied across the country. For some variables, we could not identify significant developments, e.g. total annual precipitation remained unchanged in all of Uganda. However, higher temperatures and reduced cloud cover will increase the water needs of the coffee crop, in which case water stress may rise despite unchanged water availability [30].

We carried out correlation analysis which indicated a statistically significant negative relationship between the proportion of Screen size 12 of total Robusta's and dry season precipitation between '01/02 and '16/17. In addition, observed climate at Robusta locations shows a trend to reduced rainfalls during the driest quarter of the year. Such developments should be concerning to stakeholders despite the uncertainty of this analysis owed to the short time series and the high variability of data.

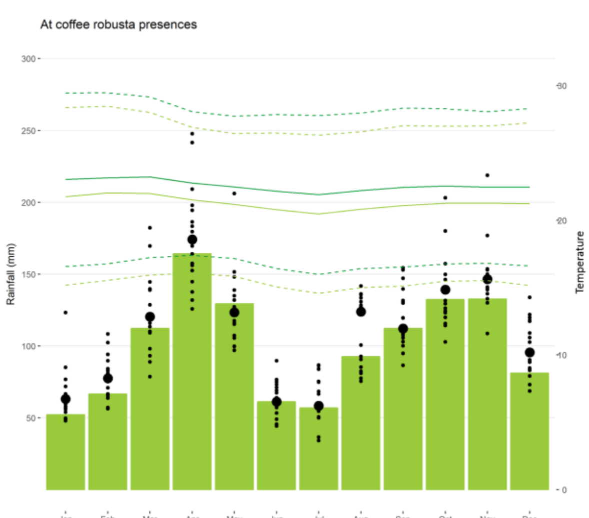


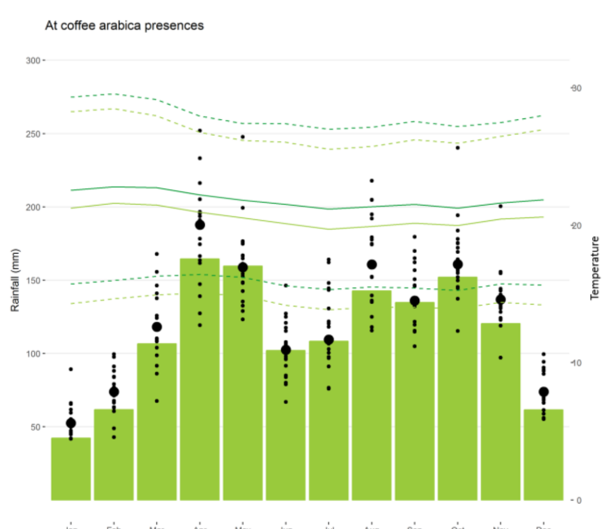
Projected climatic changes





Global climate models projected the annual mean temperature to increase by 1.7°C-1.8°C until mid-century. In line with the current trend, the increase was projected to be higher in the South-West, than in the East of Uganda. Projected increases in total annual precipitation were substantial and range from +6.8 % (South West) to +11.5% (South-East) averaged over all projections. The climate diagram that combines the current distribution of precipitation and temperature shows that there is an unambiguous trend to higher temperatures at both Arabica and Robusta locations. The seasonal distribution of rainfall will likely remain similar to today. The most likely precipitation during the dry season may be somewhat higher than currently.





This spatial pattern is contrary to already observed significant changes over the past decades. The contradiction that East Africa recently experienced a series of devastating droughts, whereas the majority of climate models predict increasing rainfall for the coming decades has been termed the East African climate paradox [28]. The reasons for this phenomenon are not well explored but are likely rooted in the complexity of the earth climate system with trans-continental couplings of climate variability. Whether or not the future climate in the region will indeed become wetter or not should, therefore, be considered an open question [29]. However, studies that reviewed model projections and observed trends show that global climate models have been consistently projecting a tendency to higher rainfall variability due to higher peak rainfall [30]. Despite the uncertainty of projections, stakeholders should prepare for more extreme rainfall and drought cycles. Such phenomena are especially of concern in Arabica regions where rainfall extremes can trigger landslides on steep slopes [31].

What is a "significant" trend?

The definition of "significance" of a climate trend by coffee practitioners is usually different from the scientific definition. A local coffee expert may claim that a trend was significant if in recent seasons weather events deviated from customary expectations, and this had an impact on crop management and yields. The scientific method was invented to test such hypotheses using systematic observation and measurement because human perception may be flawed by a few recent events that do not amount to a trend that will continue into the future, or the causality may be biased by our limited senses. However, given the urgency of climate action, scientific significance has limitations itself: a trend in climate data may be statistically significant, but meaningless to the practitioner; limited data may sometimes not allow the rigorous testing of statistical significance, especially of rare but impactful "once in a century" events. To make things complicated, start and endpoint of trend analysis may affect the detection of trends, or they may sometimes be a function of natural variability over multiple years. It is thus not good practice to assume they will continue into the future without strong evidence to support this. Last, not all local trends were caused by global warming, but are the result of deforestation, urbanization or similar localized developments.

How was the trend analysis done?

We first calculated bioclimatic indicator variables for the years 1980-2016 and then used the Theil-Sen estimator to fit a trend to the data. This method fits a line by choosing the median of the slopes of all lines through pairs of points. The Theil-Sen estimator is more accurate than least squares regression for heteroscedastic data and insensitive to outliers. We considered a trend significant if the 95% confidence interval did not include zero. We used Terraclimate [32] interpolated monthly climate data for temperature, precipitation and potential evapotranspiration. We defined the cropping year to start with the three months that are the driest of the year on the multi-decadal average and the following 9 months. For each cropping year, we derived 31 bioclimatic variables that describe annual and seasonal patterns. For each 0.05° grid cell of Uganda we evaluated the significance of the trend and estimated the slope. We picked bioclimatic variables with trends in coffee regions that could potentially have a biophysical impact. Finally, in regions with significant changes we picked a representative coffee location to determine the absolute change, p-value and slope.

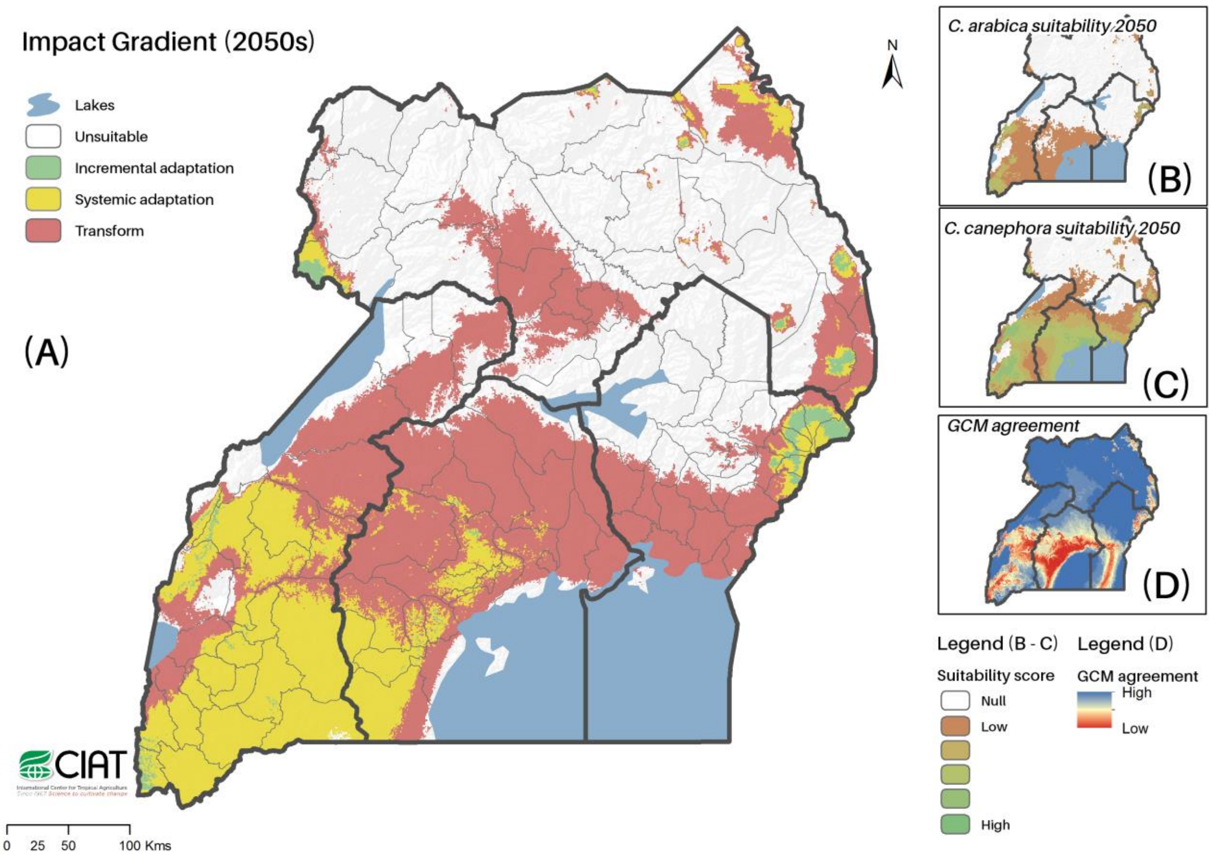
When is the dry season in Uganda?

Months with less than 50mm precipitation are generally considered a dry month for coffee. In Uganda this threshold coincides with the driest month of the year. The driest quarter begins in December for most coffee regions in Uganda, although in the Southwest driest quarter begins in June. Coffee harvest can be expected towards the end of the wet months and the highest green coffee availability may be expected during the driest quarter.

What is potential evapotranspiration?

Evapotranspiration is the combined process of evaporation from the Earth's surface and transpiration from vegetation. Potential evapotranspiration (PET) is the amount that would occur if sufficient water were available. It is estimated using average, minimum and maximum air temperature and solar radiation in the Hargreaves method [33]. The cumulative water deficit at the end of the dry season is the cumulative excess PET over precipitation.

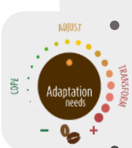
Gradient of climate change impacts



To support effective adaptation, we developed a gradient of climate change impacts for coffee production. The gradient is a coffee specific evaluation of the projected climatic changes described above. Otherwise identical climatic changes may result in severe or irrelevant impacts depending on the historic climate conditions. For example, a reduction of 50mm precipitation may be critical to the coffee crop at locations with low water availability but would be irrelevant where rainfalls are abundant throughout the year. The gradient shows the most likely degree of necessary adaptation effort across several potential future climate pathways.

The impact gradient shows that most of Ugandan coffee production can be sustained with adequate effort. Currently, about half the area in the country has suitable climate conditions for coffee production but most of the suitable area is in need of substantial adaptation efforts. Of the current Robusta area, 60% will require

Three degrees of **impacts and necessary adaptation** effort in Ugandan coffee production



- **Incremental** adaptation where climate is most likely to remain suitable and adaption will be achieved by a change of practices and ideally improved strategies and enablers, such as incentivizing greater shading or improved soil management. Altered pest and disease patterns, uncertain rainfall, drought and heat may affect the crop, but coffee production will remain feasible.
- **Systemic** adaptation where climate is most likely to **remain** suitable but with substantial stress to current production systems and adaptation will require a comprehensive change of and system redesign, along with external support for implementing changes. In Arabica areas a switch to Robusta may be commendable, in Robusta areas better adapted varieties, diversification and financial mechanisms will be needed to reduce risks.
- **Transformational** adaptation where **climate** is most likely to make Ugandan Robusta production unfeasible, and adaptation will require a redesign of production system by using varieties from other regions, or transformation to new crops. External enablers, for example agricultural extension agents and agricultural organizations, will be critical to supporting the change because the required changes are unfeasible for individual actors.

transformational adaptation, 30% systemic change, and only 1% will remain suitable using current production practices. For Arabica, impacts follow an altitudinal gradient. Areas below 1200masl will require a system change, for example to Robusta or other crops. In the future, most Arabica area will be at 1800m and above. Previously unsuitable areas above 2500m will see improved conditions.

Projected impacts on coffee production in Uganda differ when considering a Ugandan or a global perspective with important implications for adaptation interventions. Local production systems are maladapted to future conditions and without adaptation, coffee in Uganda would likely become uneconomical with climate change in most regions. However, globally, coffee production systems have been adapted to a wider range of climate conditions than currently observed in the country, suggesting that with global technology transfer, especially of germplasm, Uganda may remain suitable for coffee production. This is especially the case for Robusta production that in Uganda in the past was adapted to cool conditions when compared to other regions. Elsewhere, for example in West Africa, Robusta is produced under hotter and drier conditions with some success, suggesting that with better adapted varieties, potentially introduced from drier locations, and practices Robusta may be adaptable to the future.

How are future climate projections generated?

A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs), generally derived using global climate models. A global climate model (GCM) is a representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes. Climate projections depend on the emissions scenario used, which is in turn based on assumptions concerning future socio-economic and technological developments.

GCM outputs have a coarse resolution of 100 or 200km, which is not practical for assessing agricultural landscapes. We therefore use downscaled climate projections. For each GCM anomalies are calculated as the delta between modeled baseline climate and future prediction. These anomalies are interpolated and added to the baseline climate data. Key assumptions of this approach are that changes in climate only vary over large distances and the relationship between variables in the baseline are maintained into the future.

How was the impact gradient determined?

To determine zones of different degree of climate impact we modeled changes in bioclimatic suitability for coffee under present and 2050s climate conditions using a machine learning classification model. First, a database of locations where coffee is currently cultivated was assembled. Second, monthly climatological means of the 1950-2000 period, interpolated onto a 0.5 arcminute grid, were downloaded from the WordClim database [34] representing our current baseline climate. They were used to calculate 19 bioclimatic variables commonly used in modeling of crop suitability [35]. Third, applying Random Forests in unsupervised variation to biologically meaningful bioclimatic variables, different clusters of coffee suitability were detected within the occurrence data. These clusters can be interpreted as different climate zones all of which allow for coffee cultivation, yet under different climate conditions. Fourth, using all bioclimatic variables Random Forest classifiers were trained to distinguish between suitable areas (falling into one of the suitable climatic zones) and unsuitable areas for coffee. The classifiers were applied to climate data from for 19 climate scenarios of the 2050s from different climate models. This resulted in 19 distinct suitability maps for the 2050s.

Our modeling approach is a comparison of the distribution of climate zones in which coffee is currently produced and their distribution under future climate scenarios. This means that we considered the adaptive range currently available in Central America, but not a possible expansion of this range by novel technologies or technology transfer from other countries. Adoption of adaptive agricultural practices (e.g. novel varieties, irrigation, or shading) that expand the climatic range under which coffee may be produced profitably may result in alternative developments of the distribution of coffee in the future.

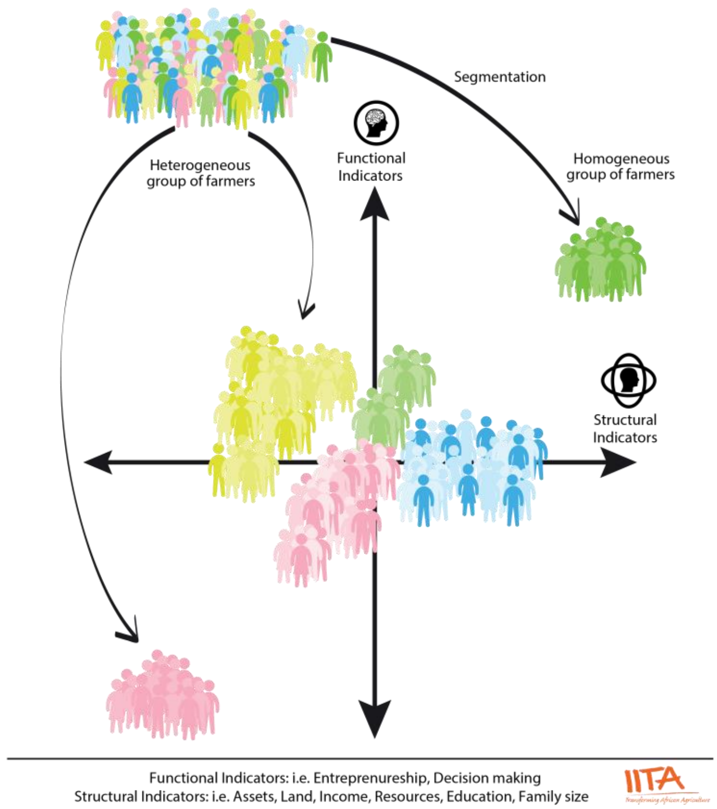
How certain is the projection?

As with any outlook, our model has a considerable degree of uncertainty and should be considered as a projection, not a prediction. Uncertainty in our model also comes from emissions scenarios, climate models and the crop model. Emissions scenarios uncertainty were discussed above, and of course, reducing emissions globally is the most promising adaptation option. We used 19 global climate models as equally valid projections of future climate. These models show a high level of agreement on an increase of temperature, but disagreement about the regional and seasonal distribution of precipitation. The resulting consensus model of the independent projections is therefore to a large degree influenced by the temperature increase while disagreement from precipitation is masked. Nevertheless, an increase in temperature implies increased water needs of agriculture. Last, our model is an "all other things equal" model that only considered a change of climate. Our statistical approach is designed to avoid overfitting and deliberately also includes marginal locations for coffee. This should be considered "friendly" uncertainty because it means through guided adaptation the worst impacts will be avoidable.

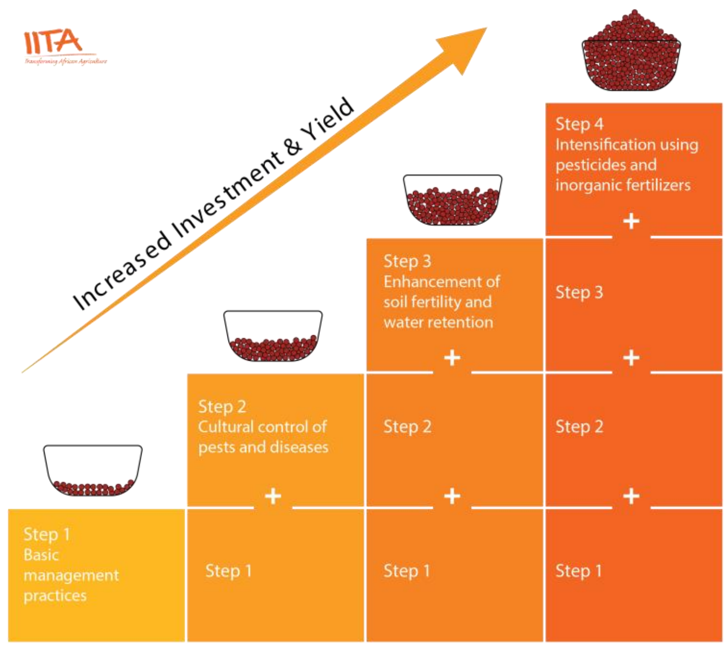
Climate smart coffee in Uganda

Farm level adaptation

To make the coffee sector in Uganda climate resilient with effective interventions at farm level, it is essential to carefully consider the individual resources and livelihood characteristics of farmers. Interventions are constrained by three issues: the extremely dispersed smallholder structure, a low level of adoption of basic management practices and the uncertain climate information. Our suggested solution are site-specific climate-smart investment pathways (CSIPs) that are aligned with the capacity and willingness to act of individual farming households [36]. CSIPs build up a sequential and incremental approach to implementing no-regret CSA practices that increase the profitability of household resources in a stepwise approach. A segmentation of farmers based on their assets and entrepreneurial characteristics helps to target farmer groups with relevant sets of practices.



The lack of adoption of CSA practices in Uganda has been ascribed to various factors, one of which is the lack of resources farmers have available to implement the broad basket of practices that are recommended in general training. By breaking down the basket into smaller, sequential and incremental steps the CSIP intends to facilitate efficient adoption for farmers.



The first step consists of low-cost approaches, and costs increase in the steps that follow. Through building up slowly, the farmer can obtain an incremental increase in yields after each step, with the aim that this yield increase will motivate farmers to re-invest part of the income from the previous harvest in the next step of the CSIP. The pathway shows how farmers can breakdown a recommended extension package for coffee farming to efficiently increase yield.

The CSIP requires an understanding of the different needs of the various farmer's types. The farmer segmentation tool is a way to highlight this heterogeneity of farmers. Designing extension processes that cater to these differences will help improve adoption of CSA practices. Farmers are segmented based on structural (resource endowments) and functional (entrepreneurship) indicators. Farmer segmentation is likely to vary between project regions and should be carried out when designing appropriate CSIPs for project interventions.

Renovation with adapted varieties

Renovation and rehabilitation (R&R) of poor yielding coffee trees with improved varieties that are tolerant of abiotic stress or resistant to important disease threats is a key tool to maintain a high coffee productivity in a changing climate. In Uganda renovation is usually done by replacing diseased or dead trees with seedlings.

The President of Uganda tasked the coffee sector with distributing 300 million seedlings per year for three years from 2016-2019 with the support of the Ministry of Defense. The UCDA (Uganda Coffee Development Authority) coordinated the mass production of seedlings with resistance to CWD. Survival rates of the seedlings were low. As a result of this policy, farmers' interest in alternative sources of varietal material is low.

Climate change adaptation has not been an objective during the development of locally available varieties. Recently efforts have been initiated by NaCORI to screen available planting material for drought tolerance, but currently little systematic information exists.

There may be some efforts to exchange germplasm with Ghana, but negotiations would be advancing slowly. Our, and other, research suggests that such an exchange could increase the resilience of Ugandan varieties to drier and hotter conditions. Poncet et al (in preparation) were able to show that West African Robusta varieties are genetically distant from Ugandan populations and are less vulnerable to climate change.

World Coffee Research (WCR) is expanding a program for verified seedling material to Uganda. From certified nurseries healthy and genetically verified Arabica varieties could be obtained.

Systems approaches

To be successful, planning and implementation of interventions for climate-smart practices in Uganda need to consider the system in which coffee producers make their decisions. Informal land tenure, gender relationships, and poor market access are disincentives for CSC adoption.

Secure and equitable land ownership rights are necessary conditions for sustainable development. Multiple initiatives are ongoing to foster tenure security through better land demarcation or the delivery of adequate documentation to landowners. Greater use could be made of GPS-data, and of technologies such as drones to reduce the time and costs for data collection in the field [14]. For example, the **German GIZ** cooperates with Ugandan authorities in their Responsible land policy project [37] to strengthen the legal security of farmers.

A change in practices often affects the gender division of labor. The **Hanns R. Neumann Stiftung (HRNS)** uses interactive **Couple Seminars** in which couples jointly develop solutions for imbalances in their joint decision-making and resource allocation. After the seminars, **Change Agents** receive further support and act to promote the positive outcomes of cooperative decision making within their communities [38]. Their encouragement of participatory decision making has been shown to result in greater investment in sustainable intensification, more balanced control over cash crop income and improved livelihoods [39].

The complex value chain in Uganda transmits a relatively high share of the FOB price to farmers, but access to premiums for quality or sustainable practices require functional organizational structures. The **HRNS** project **Uganda Coffee Farmer Alliance (UCFA)** [40] builds capacity at multiple levels with the objective of enabling farmers to add value to produce and collectively access services and inputs. Locally, village groups of 20-30 farmers organize joint training and coffee collection. At county level, depot committees represent up to 800 farmers. HRNS increases their organizational capacity to bulk, process and market coffee. The UCFA serves as an apex body to these farmer companies and has a coordinating role, including codes of conduct and service provision [41].

Ecosystem-based adaptation (EbA) is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. Many farm-level practices have external benefits when implemented at landscape scale. In addition, the restoration of degraded areas or forest patches, or protection of riparian vegetation can improve the resilience of a landscape. Such measures aid to keep moisture in the landscape and can effectively reduce temperature [42].

Finally, coffee producers at locations that are severely affected by climate change will need income alternatives. **Diversifying production** can be a measure to reduce climate shock risk to household income. However, oftentimes field crops don't offer the same income and ecosystem services benefits as coffee. Other tree crops are therefore preferential. The development of alternative or complementary value chains that can replace lost coffee income will require multi-stakeholder approaches that include public and private actors.

Enabling interventions

Enabling interventions facilitate and support the adoption of climate-smart technologies and practices by providing services and finance to farmers.

Common finance mechanisms for smallholders in Uganda are **Savings and Credit Cooperatives and Mobile money.** SACCOs are a primary source of finance although they are not necessarily aimed at agriculture. Average savings are about USD 30, embezzlement and low regulation are issues [43].

Mobile money services such as SmartMoney provide low-cost access to transactions and finance to farmers. MM users sell a larger proportion of their coffee as shelled beans to buyers in high-value markets, instead of selling to local traders immediately after harvest and as a result have higher incomes [44]. Mobile Money solutions in Uganda suffer from unclear and changing regulation [14].

A smart alignment of management practices with seasonal patterns can avoid losses of input and labor due to untimely weather events. **Weather related management alerts** combine season-based cropping calendars with weather station data to trigger mobile service messages. Instead of initiating management following the normal seasonal rhythm, the alerts advise practices such as planting or fertilization when the observed weather suggests a suitable crop development state.

Index-based weather insurance offers a new promise for reducing climate risks. Payouts are triggered by pre-determined weather events and thus do not require verification of losses. Such index insurance may avoid problems of adverse selection and moral hazard. It also has minimal transaction costs, which helps the insurance market reach poor people. A properly designed index could address the wide variation in yields and quality that is so central to coffee profits. However, index insurance has met with low uptake among intended beneficiaries, particularly small-scale farmers. Weak regulations, weather data quality and a lack of local adaptation and capacity building between insurers, farmers, and regulators are some of the challenges faced by this intervention [45]. An index-based insurance contract targeting at the group level, such as a coffee cooperative, could be a potential solution to the problem of low uptake.

A major reduction in deforestation is needed to mitigate climate change and biodiversity loss in Uganda. Climate Smart Coffee has to eliminate deforestation from the supply chain. To achieve broader impact **zero-deforestation policies** companies need to avoid leakage, lack of transparency and traceability, selective adoption and smallholder marginalization. There are ambitions to develop real time deforestation monitoring and early detection warnings for Uganda that can be used by public and private stakeholders to improve the detection of coffee driven deforestation [46].

Adoption and scaling business cases

Active efforts to scale out climate-smart practices are a priority to secure the long-term sustainability of the coffee sector. Because coffee production is an investment of several decades and many CSA practices have a long lead-time, adaptive action needs to be taken immediately with forward-looking thinking. A multi-stakeholder approach will be required as no single technology or scaling pathway may account for the diversity of decision environments of the actors involved. Together with organizational development, we suggest complementary scaling pathways for climate smart coffee that respond to business incentives: Voluntary certification, carbon insetting, impact investing, and sustainability branding.

Certifiers act both as a verification body of sustainable practices and providers of training. Certifiers' interest in climate adaptation is grounded on the premise that the final consumer is willing to pay a premium for certified products. Currently, only 3% of Ugandan coffee exports are certified by Rainforest Alliance, Organic and Fairtrade International. Certified farmers tend to have longer coffee farming experience, access to inputs and agricultural extension, however, high certification costs and small farm sizes hinder the expansion of certification [47]. By facilitating access to certification to those smallholders that are organic by default, certifiers would be able to provide economic incentives and innovative training to a large segment on farmers.

Management practices such as shade use and reforestation have the double benefit of both reducing climate vulnerability and increasing carbon stocks in coffee. In some cases, these synergies can be used to incentivize and subsidize adaptation actions through carbon accounting for mitigation actions. Carbon insetting offers to offset GHG emission in the coffee supply chain or processes.

Therefore, roasting and trading companies can offset their GHG footprint by investing in carbon sequestering activities at farmer level that at the same time support the adaptation of farmers to progressive climate change. A study in Nicaragua showed that afforestation of degraded areas with coffee agroforestry systems and boundary tree plantings resulted in the highest synergies between adaptation and mitigation [48]. Financing possibilities for these joint adaptation mitigation activities can arise through carbon offsetting, carbon insetting, and carbon footprint reductions.

The interest of companies to invest in CSC depends on their business model and the scale of their operations. Companies that work closely with farmers tend to not separate efforts into climate or sustainability efforts, but rather focus on holistic programs to increase productivity and make coffee farming attractive. Large brands source large quantities and choose to invest in climate change activities out of a volumes-based business case. "Front-runner" companies are concerned about supply volumes, but in addition, generate value from brand reputation. Last, the value of smaller brands is often based on social and environmental reputation. Therefore, the latter have a higher capacity to develop solutions in direct contact with their smallholder base than the larger companies. They can, therefore, act as catalysts to innovate CSC approaches that can be mainstreamed by the more risk-averse large brands with their large constituencies to achieve CSC adoption at scale (See case study below for a practical example).

Social investment funds seek to maximize positive social and environmental effects of investments by providing finance for rural small businesses for both short- and long-term investments. The main impact investment agencies annually loan about USD 15m to coffee producer organizations in Uganda [49]. Impact investors are more able to act on novel information than governmental organizations but some degree of certainty about the efficacy of practices is required. Working with producer organizations rather than individual farmers may provide efficient incentives for adoption of financeable CSC. However, currently incentive investors are limited in their constituencies.

Policy Environment

Institutions

The main national level institution is the **Ministry of Agriculture, Animal Industries and Fisheries (MAAIF)**, including its main directorates and departments. The institutional capacity within MAAIF to do policy analysis, monitoring and evaluation is presently weaker than it was 30 years ago, when agriculture was at the center of hopes for a rebirth of economic growth. While having a central role, MAAIF is neither the main decider on policies, nor is it the sole implementer [14].

The **National Agricultural Advisory Services (NAADS), now disbanded,** was a semi-autonomous public agency within the MAAIF, responsible for public agricultural advisory/extension services. It was created in 2001 to improve rural livelihoods by increasing agricultural productivity and profitability [50]. The UPDF (Uganda Peoples Defence Forces) took over NAADS in 2014, although its ongoing operation is unclear.

The **Uganda Coffee Development Authority (UCDA)** is a development and regulatory body with the objective to promote and oversee the coffee industry in Uganda [13]. UCDA develops research mandates, controls quality and supports the marketing of Ugandan coffee. With its ~40 staff for productivity development, UCDA supports the organization of farmers and provides training to about 60000 households.

The **National Coffee Research Institute (NaCORI)** is mandated to conduct research on coffee and cocoa. NaCORI develops agronomic and genetic technologies, material and knowledge to enhance the production and quality of coffee (Arabica and Robusta) in Uganda [51]. It rarely provides training, but it develops management advice and is engaged in the large-scale production of seedlings and selection of pest and disease resistant cultivars. NaCORI provides inputs to UCDA's regulations.

The main mandate of the **Ministry of Defense** is to protect the sovereignty of Uganda, but it was also tasked to 'engage in productive activities for natural development'. The MoD leads the **Operation Wealth Creation Program** [52] alongside its military branch, the UPDF, in which several hundred million seedlings are distributed to farmers.

Ministry of Water and Environment hosts the **Climate Change Department** [53], created in 2008 to implement Uganda's Kyoto Protocol commitments. Its role is to coordinate national climate change actions (Mitigation and Adaptation) in different sectors.

The **Uganda Coffee Farmers Alliance (UCFA)** is a farmer-owned apex body established to provide marketing and other support services to coffee farmers organizations in Uganda. UCFA improves linkages with extension service providers, researchers, input suppliers, financial institutions and others [41].

The **National Union of Coffee Agribusinesses and Farm Enterprises (NUCAFE)** [54] is an umbrella for 200 cooperatives and associations. Its activities focus on strengthened organizational and value additional capacity of farmers.

The **Uganda Coffee Federation (UCF)** is a non-profit company that organizes private sector stakeholders towards a sustainable and reputable coffee business in Uganda. It members include coffee exporters, coffee processors, farmers, input suppliers, traders, and insurance companies [55].

Café Africa is a non-profit association founded in 2006. Café Africa supports multi-stakeholder processes including all members of the coffee value chain and to aim for sector change. Its vision is economic prosperity through sustainable coffee production [56].

About 20% of coffee farmers are members of the 10000+ **Savings and Credit Cooperatives** (SACCOs) in Uganda [11]. These cooperatives are the primary source of finance for smallholders although they are not necessarily aimed at agriculture. Average savings are about USD 30, embezzlement and low regulation are an issue [43].

Larger farmers would prefer official bank loans, but these are available only to a small subset of farmers. In the coffee roadmap (see below), a coffee farmers finance program by the **Central Bank** is called for but at the time of writing, there were no details available about this. Currently, the Agricultural

Credit Facility by the Bank of Uganda provides agricultural loans for farmers at an interest rate of 10 percent per annum, with a maximum grace period of three years.

Policies

The **National Coffee Bill of 2018** replaced the Uganda Coffee Development Authority Statute of 1994. The new law is intended to promote coffee research, good farming practices, domestic consumption and value addition. It is meant to streamline and harmonize the roles of coffee institutions and strengthen the role of UCDA. However, some voices claim that its impact on the industry will be limited [57].

At the time of writing, a **Climate Change Bill** was being negotiated to provide for a regulatory framework for implementation of climate change adaptation activities. It would strengthen the Climate Change Department and provide it with a stronger mandate to enable it to coordinate, supervise, regulate, and manage all activities related to climate change [58].

Main existing initiatives

Operation Wealth Creation (OWC) was launched in 2013 as an intervention to "facilitate national socio-economic transformation, with a focus on raising household incomes and wealth creation by transforming subsistence farmers into commercial farmers to end poverty" [52]. In cooperation with NaCORI and UCDA, OWC distributed 300 million coffee seedlings to households across the country. Approximately 60% of the seedlings died because of improper transportation and untimely delivery during the intervention [59].

The **Coffee Roadmap 2020** is the result of a directive by the president to accelerate coffee production from the current 3.5-4.5 million 60 kg bags to 20 million bags by 2020. The roadmap aims to quadruple productivity, add 20% area and add 15% higher value to Ugandan coffee by 2025-2030 [60]. The roadmap consists of 9 key initiatives that include improved domestic and international demand, a strengthening of farmer organizations and producer cooperatives, concessions for coffee production on large underutilized land, improvement of planting materials, improved access to quality inputs and development of a coffee finance program with the Central Bank and Treasury.

The **Prosper Africa initiative** by the Council on Smallholder Finance (CSAF) is a multi-stakeholder initiative that will address immediate barriers to finance and generate investments in agricultural small and medium enterprises (SME). The initiative seeks to increase capital for lending, expand demand and strengthen institutions for SME finance. The private sector will get better access to finance solutions for agriculture to invest in their smallholder base [49].

Because of the weak capacity of the public sector to provide effective training, the role of the private sector is important. To name one, **TechnoServe** together with **Enveritas** plan to train approximately 30000 farmers in Uganda over 4 years in improved coffee agronomy. The project identified innovative solutions to agronomic problems and trains farmers in good agricultural practices. Companies that are known to actively engage Uganda coffee smallholders are **Ugacof** and **Kawacom**. Other examples are **Kyagalanyi** and **OLAM** that train farmers in CSC practices, or the already mentioned **HRNS** foundation which implements programs with European trading houses.

Outlook

Private sector initiatives have the potential to contribute to effective adaptation and reduced emissions, ideally jointly with supportive public policies. Low adoption rates of climate-smart practices may be a challenge due to the unclear business case. Producers must typically bear most of the costs of shifting towards climate-smart production systems and do not always perceive the benefits. To increase adoption, compliance with sustainability requirements must be economically and technically feasible for producers. Supply-chain initiatives can have unintended social consequences by entrenching positions of powerful actors and excluding smallholders and indigenous groups from market access when standards non-compliance is criminalized. Climate change may further marginalize poorer producers, as farmers with good access to capital and technology are more likely to be able to manage emerging climate risk.

Private sector initiatives must continue to engage in climate-smart programs, encourage smallholders to participate and avoid their exclusion. This requires that all value chain actors, not just the producers or processors, share costs and risks.

Case study:

Integrating CSA practices

William Bunjjo owns a farm of 4ha in Kyabakadde, part of the district of Mukono in the Central Region of Uganda. About 1.5ha are used for Robusta production, 2ha are used for timber and plantain production, the remainder is used for other food crops. He is 72 years old and lives with 10 of his children. On the farm they produce everything they consume and generate the cash they need to pay school fees. Children that have left the farm support the family with remittances.

"Coffee production was always difficult until about 20 years ago I started to receive technical assistance. That is when things really changed. I used to have many problems but when I received new seedlings I was able to produce more and a higher quality. Since then I started to attend trainings and I learned a lot, I even became a trainer myself and pass on my knowledge to others and I teach my children.

We use very simple tools on our farm, I really use my hands and we don't use any machines. About three years after receiving the training I started to implement the practices on my farm. We use mulch from the other farm plots, installed trenches and keep the trees on our farm. We put Matoke in between the coffee. We eat most of the Matoke but sell some of it as well.

I'm supposed to have about 1200 trees per hectare but there are less now because I had to take some out. All my trees are of different age. I already had coffee when I had to take a lot out 20 years ago because of diseases and planted improved seedlings. Every year we replant diseased trees. Since a few years I see a lot of Wilt disease and I now have a lot of gaps in my farm. But when the government came and distributed seedlings I refused them. We need them when the rain comes but they brought them when the dry season starts, and I didn't have water to irrigate.

Over the past years the weather has really become more and more difficult. Not even the weather forecast works anymore. Previously rain was predictable but now you can't know when the rain comes. It is dry when it is supposed to rain and then a lot of rain comes at once. The trenches are good but not all my neighbors use them so sometimes it is too much, and the rain causes damages.

Maybe 5 of my 20 neighbors have trenches but I understand that it is difficult. Some have only very small farms and others work so much on other farms that they forget to take care of their own. Most of them have also cut down their trees and sold them for easy money. Some have used it for school but most just bought food. They think the trees just grow back but this doesn't happen.

Because of my trainings, I can do many things but when the drought comes, I can't do much. The harvest is low and most others have a low quality. My quality is better, but I still receive a low price because the price is set equally for everyone by the middlemen. When the company was still here this was different, and a better quality received a better price, but about 4 or 5 years ago they went away. The extensionists don't come anymore. They show up but never follow up and then they bring seedlings when we don't need them. We need better training because training gives us hope. Without training, we don't have hope.

Literature

1. FAO. FAOSTAT [Internet]. 2018 [cited 1 Aug 2018]. Available: http://www.fao.org/faostat/en/#home

2. UCDA. Statistics | Uganda Coffee Development Authority [Internet]. 2018 [cited 5 Sep 2018]. Available: https://ugandacoffee.go.ug/statistics

3. Uganda Bureau of Statistics. 2017 Statistical Abstract. 2018.

4. Food and Agriculture Organization of the United Nations. Global forest resources assessment 2015: how are the world's forests changing? 2016.

5. FAO. Global Forest Ressources Assessment Country Report, Uganda [Internet]. Rome; 2015. Available: http://www.fao.org/forest-resources-assessment/current-assessment/country-reports/en/

6. Bukomeko H, Jassogne L, Tumwebaze SB, Eilu G, Vaast P. Integrating local knowledge with tree diversity analyses to optimize on-farm tree species composition for ecosystem service delivery in coffee agroforestry systems of Uganda. Agrofor Syst. 2017; doi:10.1007/s10457-017-0172-8

7. Negawo WJ, Beyene DN. The Role of Coffee Based Agroforestry System in Tree Diversity Conservation in Eastern Uganda. J Landsc Ecol. 2017;10: 1–18. doi:10.1515/jlecol-2017-0001

8. Global Coffee Platform. Uganda - A quick scan on improving the economic viability of coffee farming [Internet]. 2018. Available: https://www.globalcoffeeplatform.org/assets/files/Resources/Uganda-Deliverable_vSent.pdf

9. Uganda National Bureau of Standards. Draft Uganda Standard - Green coffee beans. 2018.

10. Uganda Bureau of Statistics. Uganda National Panel Survey (2013-2014). Living Standards Measurement Study [Internet]. 2016. Available: http://microdata.worldbank.org/index.php/catalog/2663/data_dictionary

11. Anderson J, InterMedia Survey Institute, LSMS Team. CGAP Smallholder Household Survey 2015 [Internet]. Uganda; 2015. Available: http://microdata.worldbank.org/index.php/catalog/2574/study-description

12. Cool Farm Tool | An online greenhouse gas, water, and biodiversity calculator [Internet]. [cited 12 Apr 2018]. Available: https://coolfarmtool.org/

13. UCDA. Corporate plan 2015/16 – 2017/18. 2014.

14. World Bank. Closing the Potential-Performance Divide in Ugandan Agriculture. Washington, D.C., U.S.A.: World Bank; 2018.

15. Uganda Property Rights and Resource Governance [Internet]. USAID; Available: https://www.land-links.org/wp-content/uploads/2016/09/USAID_Land_Tenure_Uganda_Profile.pdf

16. Statistics UB of. The national population and housing census 2014–main report. UBOS Kampala, Uganda; 2016.

17. Ochago R. Barriers to women's participation in coffee pest management learning groups in Mt Elgon Region, Uganda. Yildiz F, editor. Cogent Food Agric. 2017;3. doi:10.1080/23311932.2017.1358338

18. Bolwig S. Poverty and gender effects of smallholder organic contract farming in Uganda. 2012;

19. Baffes J. Restructuring Uganda's coffee industry: why going back to basics matters. Dev Policy Rev. 2006;24: 413–436.

20. Latynskiy E, Berger T. Networks of Rural Producer Organizations in Uganda: What Can be Done to Make Them Work Better? World Dev. 2016;78: 572–586. doi:https://doi.org/10.1016/j.worlddev.2015.10.014

21. Ombogoh DB, Tanui J, McMullin S, Muriuki J, Mowo J. Enhancing adaptation to climate variability in the East African highlands: a case for fostering collective action among smallholder farmers in Kenya and Uganda. Clim Dev. 2018;10: 61–72. doi:10.1080/17565529.2016.1174665

22. Nabeta NE. Coping with coffee wilt disease (Tracheomycosis) in Uganda [Internet]. MASTER OF SCIENCE IN AGRICULTURAL ECONOMICS, MAKERERE UNIVERSITY. 2007. Available: https://dumas.ccsd.cnrs.fr/dumas-01277887

23. Kagezi HG, Kucel P, Egonyu PJ, Nakibuule L, Kobusinge J, Ahumuza G, et al. Impact of the black coffee twig borer and farmers' coping mechanisms in Uganda. 11th Afr Crop Sci Proc Sow Innov Sustain Food Nutr Secur Afr Entebbe Uganda 14-17 Oct 2013. 2013; 285–292.

24. Bukomeko H, Jassogne L, Kagezi GH, Mukasa D, Vaast P. Influence of shaded systems on *Xylosandrus compactus* infestation in Robusta coffee along a rainfall gradient in Uganda: Shaded coffee systems and X. compactus. Agric For Entomol. 2018;20: 327–333. doi:10.1111/afe.12265

25. Liebig TI. Abundance of pests and diseases in Arabica coffee production systems in Uganda-ecological mechanisms and spatial analysis in the face of climate change. 2017.

26. Avelino J, Allinne C, Cerda R, Willocquet L, Savary S. Multiple-Disease System in Coffee: From Crop Loss Assessment to Sustainable Management. Annu Rev Phytopathol. 2018;56: 611–635. doi:10.1146/annurev-phyto-080417-050117

27. Jaramillo J, Muchugu E, Vega FE, Davis A, Borgemeister C, Chabi-Olaye A. Some Like It Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (Hypothenemus hampei) and Coffee Production in East Africa. Thrush S, editor. PLoS ONE. 2011;6: e24528. doi:10.1371/journal.pone.0024528

28. Rowell DP, Booth BBB, Nicholson SE, Good P. Reconciling Past and Future Rainfall Trends over East Africa. J Clim. 2015;28: 9768–9788. doi:10.1175/JCLI-D-15-0140.1

29. Lyon B, Vigaud N. Unraveling East Africa's Climate Paradox. Patterns Clim Extrem Trends Mech. 2017; 265–281.

30. Zhao T, Dai A. Uncertainties in historical changes and future projections of drought. Part II: model-simulated historical and future drought changes. Clim Change. 2017;144: 535–548. doi:10.1007/s10584-016-1742-x

31. Mugagga F, Kakembo V, Buyinza M. Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. CATENA. 2012;90: 39–46. doi:10.1016/j.catena.2011.11.004

32. Abatzoglou JT, Dobrowski SZ, Parks SA, Hegewisch KC. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Sci Data. 2018;5: 170191. doi:10.1038/sdata.2017.191

33. Hargreaves G, Allen R, Hengl T, Jesus J, MacMillan R, Batjes N, et al. History and Evaluation of Hargreaves Evapotranspiration Equation. J Irrig Drain Eng Httpsdoiorg101061ASCE07339437129153 SoilGrids1kmglobal Soil Inf Based Autom Mapp PloS One 98 E105992 Httpsdoiorg101371journalpone0105992. 2014;129: 53–63.

34. Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. Very high resolution interpolated climate surfaces for global land areas. Int J Climatol. 2005;25: 1965–1978.

35. Nix HA. A biogeographic analysis of Australian elapid snakes. Atlas Elapid Snakes Aust R Longmore. 1986; 4–15.

36. Jassogne L, Mukasa D, Bukomeko H, Kemigisha E, Kirungi D, Giller O, et al. Redesigning Delivery: Boosting Adoption of Coffee Management Practices in Uganda. The climate smart investment pathway approach and the farmer segmentation tool. 2017;

37. giz. Responsible land policy [Internet]. [cited 22 Nov 2018]. Available: https://www.giz.de/en/worldwide/39918.html

38. Gender. In: Hanns R. Neumann Stiftung [Internet]. [cited 22 Nov 2018]. Available: https://www.hrnstiftung.org/gender/

39. Lecoutere E, Jassogne L. "We're in this together": Changing intra-household decision making for more cooperative smallholder farming. 2016;

40. Lecoutere E. Building Coffee Farmers Alliances, Uganda. In: Hanns R. Neumann Stiftung [Internet]. [cited 22 Nov 2018]. Available: https://www.hrnstiftung.org/project/building-coffee-farmers-alliances/

41. Uganda Coffee Farmers Alliance [Internet]. [cited 27 Sep 2018]. Available: http://ucfa.or.ug/index.php?option=com_content&view=frontpage

42. The CASCADE Program: Ecosystem-based Adaptation for Smallholder Subsistence and Coffee Farming Communities in Central America - Conservation International [Internet]. [cited 12 Apr 2018]. Available: https://www.conservation.org/projects/Pages/cascade-program.aspx

43. Schmidt O. How cooperative are savings and credit cooperatives in developing countries?: An analysis of datasets from Uganda: How coperative are SACCOs? Ann Public Coop Econ. 2017;88: 345–368. doi:10.1111/apce.12155

44. Sekabira H, Qaim M. Mobile money, agricultural marketing, and off- farm income in Uganda. Agric Econ. 2017;48: 597–611.

45. Ntukamazina N, Onwonga RN, Sommer R, Rubyogo JC, Mukankusi CM, Mburu J, et al. Index-based agricultural insurance products: challenges, opportunities and prospects for uptake in sub-Sahara Africa. 2017;

46. Terra-i. Terra-i Honduras. In: Terra-i.org [Internet]. [cited 13 Apr 2018]. Available: http://www.terra-i.org/terra-i/data/data-terra-i_honduras.html

47. Chiputwa B, Spielman DJ, Qaim M. Food standards, certification, and poverty among coffee farmers in Uganda. World Dev. 2015;66: 400–412.

48. Rahn E, Läderach P, Baca M, Cressy C, Schroth G, Malin D, et al. Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies? Mitig Adapt Strateg Glob Change. 2014;19: 1119–1137.

49. 2018 State of the Sector | CSAF [Internet]. [cited 27 Sep 2018]. Available: https://www.csaf.net/state-of-the-sector/

50. NAADS: National Agricultural Advisory Services [Internet]. [cited 7 Sep 2018]. Available: http://www.naads.or.ug/

51. National Coffee Research Institute (NaCORI) [Internet]. [cited 7 Sep 2018]. Available: http://www.nacori.go.ug/

52. MoD Uganda. Operation Wealth Creation [Internet]. 2018 [cited 7 Sep 2018]. Available: http://owc.co.ug/

53. Climate Change Department. In: Climate Change Department [Internet]. 2018 [cited 7 Sep 2018]. Available: http://ccd.go.ug/about-us/

54. Home | NUCAFE: National Union of Coffee Agribusinesses and Farm Enterprises [Internet]. [cited 10 Jan 2019]. Available: http://www.nucafe.org/index.php

55. Uganda Coffee Federation (UCF) - Uganda Coffee Federation [Internet]. [cited 7 Sep 2018]. Available: https://ugandacoffeefederation.org/

56. Cafe Africa [Internet]. [cited 7 Sep 2018]. Available: http://www.cafeafrica.org/

57. The National Coffee Act of 2018: A sour cup of Coffee or just another Robusta? In: MinBane [Internet]. 22 May 2018 [cited 7 Sep 2018]. Available: https://minbane.wordpress.com/2018/05/22/https-wp-me-p1xtjg-6zi-2/

58. The national climate change bill - draft [Internet]. Jul 26, 2017. Available: https://de.scribd.com/document/356357987/Draft-Uganda-Climate-Change-Bill-2017-Ver-July-2017

59. Magombe A. Strengthening Coffee Seedling Survival (SCSS) Project. 2018 Mar; Uganda.

60. The genesis of the Coffee Roadmap | Uganda Coffee Development Authority [Internet]. [cited 7 Sep 2018]. Available: https://ugandacoffee.go.ug/genesis-coffee-roadmap

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