



## Research article

# Cost-benefit analysis of prioritized climate-smart agricultural practices among smallholder farmers: evidence from selected value chains across sub-Saharan Africa



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## ABSTRACT

Prioritization of adaptation options is complex. This study presents a multi-dimensional framework to evaluate how to allocate resources among competing alternatives. The main objectives of the study were to identify the prioritized climate-smart agricultural practices adopted among smallholder farmers in different value chains across sub-Saharan Africa (SSA) and to assess the economic feasibility of the practices using Cost-Benefit Analysis (CBA) to develop a portfolio of viable and cost-effective options. This study focused on selected five SSA countries and selected value chains. 153 smallholder farmers and stakeholders were interviewed. The Climate Smart Agriculture Prioritization Framework was applied for the assessment of economically viable adaptation options. The prioritization was based on standard ranks on the ability of the practice to improve productivity, increase resilience, and mitigation. Spearman's rank-order correlation was used to assess the independence of the ranks. A CBA was conducted as the final step. Smallholder farmers in the study areas prioritized the adoption of improved seed, good agricultural practices, and conservation agriculture practices. In the sweet potato value chain in Kenya, good agricultural practices was viable with an NPV of US\$ 28,044, an IRR of 328%, and a one-year payback period. This is in comparison to the improved seed varieties (US\$ 8,738, 111%, and two years payback period) respectively. In Nigeria, the most viable option was the improved seed in the potato value chain and good agricultural practices in the rice value chain. In Malawi, Ethiopia, and Zambia, the most viable practices were improved seed, and conservation agriculture in the soybean, faba beans, and peanut value chains respectively. The NPV was highly sensitive to changes in the discount rate, moderately to price, yield, and practice lifecycle, and least to changes in annual labour costs. The results elaborate on the most feasible adaptation practices that enable smallholder farmers to increase productivity and be economically efficient. The use of the CSA-PF consecutively with the CBA tool allows for the proper identification of best-bet CSA options.

## 1. Introduction

Smallholder farmers in sub-Saharan Africa (SSA) are most vulnerable to the risks posed by climate change. This is due to over-reliance on rain-fed agricultural systems and low adaptive capacity attributed to high poverty incidences. Dube et al. (2016) estimated that yield from rain-fed agriculture could decrease by about 50% in the next 30–35 years if adaptation measures are not put in place. With the advent of climate change, if we continue with business as usual (BAU), rain-fed agricultural production systems may not be sustainable. Climate change adaptation

through promoting the adoption of Climate-Smart Agriculture (CSA) practices is an effective policy recommendation to deal with the risks posed by climate change. CSA, as defined by the Food and Agricultural Organization of the United Nations (FAO) is an approach for developing agricultural strategies to secure sustainable food security under a changing climate (FAO et al., 2018).

Smallholder farmers experience climate shocks such as droughts, floods, strong winds, extreme rainfall events, and tropical cyclones. To reduce vulnerability to these shocks, the governments of most SSA countries have developed policies and strategies that promote

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sustainable agricultural production practices. For example, practices under Sustainable Land and Water Management include but are not limited to; minimum or no-tillage practices, construction of terraces, soil bunds, stone or vegetation bunds, Half-moons<sup>1</sup>, and Zai pits<sup>2</sup>, mulching, on-farm storage facilities, irrigation, System of Rice Intensification (SRI), and alternate wetting and drying in rice production (Cai et al., 2019; Oremo et al., 2020). Practices aimed at pest and weed management include the use of pesticides, new crop varieties or cultivars that are pest and disease resistant, adoption of push-pull technology, and crop diversification through intercropping or crop rotation (Agula et al., 2019). Other practices include agroforestry and cover cropping, changing of planting dates, index-based insurance, and use of organic manure among others. All these are aimed at income diversification, risk management, and enhancing soil carbon, fertility, and infiltration capacities (Hansen et al., 2019).

Well-designed CSA strategies, therefore, contribute to ensuring sustainability and future food and nutrition security (Minang et al., 2015). However, the uptake and upscaling of CSA practices in SSA are still very low. Several factors constrain the uptake of CSA practices among smallholder farmers in SSA. These include high initial investment, input, and operational costs, limited access to technology and information, minimal gains over short periods, trade-offs between productivity, sustainability, and environmental protection, inadequate information on seasonal climate forecast trends, and inadequate coordination along agricultural value chains among others. These factors increase the vulnerability of smallholder farmers by preventing them from effectively adopting CSA practices that have the potential to improve their food, nutrition, and adaptive capacity.

This paper evaluates the costs vis a vis the benefits associated with prioritized climate adaptation practices among smallholder farmers for selected value chains in five SSA countries. Prioritization of CSA practices is an essential component in decision-making analysis as it allows for consideration of local context-specific and system characteristics. For prioritization to be successful, a minimal dataset of economic yield, inputs used, the costs and benefits associated is required (Dunnett et al., 2018). Prioritization helps in identifying, through suggested criteria, the importance that farmers place on a particular adaptation strategy. The criteria include the initial investment costs, the payback period, and the importance of the practice in increasing productivity. These are highly crop/strategy/country-specific. The prioritization process is robust and helps to identify the most important strategies that increase productivity and resilience for smallholder farmers as well as contribute to the mitigation of greenhouse gas (GHG) emissions from the agricultural sector.

This study aimed to develop a portfolio of feasible CSA practices that will help all stakeholders including policymakers make informed decisions in choosing among competing alternatives. Most research on climate change stresses and adaptation strategies often lacks an economic feasibility test. This study sought to fill this knowledge gap by including a Cost-Benefit Analysis (CBA) in the identification of appropriate CSA strategies. This was achieved through evaluating two objectives: (i) to identify the prioritized adaptation strategies among smallholders in the five SSA countries, and (ii) to assess the economic feasibility of the prioritized CSA practices using cost-benefit analysis. The Climate-Smart Agriculture Prioritization Framework (CSA-PF) was applied. CSA-PF is a multi-dimensional process. It provides a step-by-step methodology to identifying the main CSA practices and involves a ranking process to identify the prioritized ones. It also involves the assessment of the costs and benefits of the prioritized CSA practices as a final step of the process.

CBA is a decision-making tool that aids in evaluating the economic feasibility of investment by assessing the costs and comparing them with the benefits. In recent years CBA has been applied in climate adaptation studies to estimate the economic profitability of selected climate

adaptation practices. In the context of this study, we applied the CBA tool to CSA practices. CBA indicates whether a CSA option is efficient compared to the BAU (Ng'ang'a et al., 2020). It can either be financial or economic. Economic CBA considers both private profitability and the social and environmental effects (externalities). Economic CBA is ideal. However, in this study, we consider financial CBA and evaluate the private profitability of prioritized CSA practices. The externalities (positive or negative) are however discussed using information from case studies in different SSA regions.

CBA can be done ex-ante (before implementation) when investment in CSA practice is under consideration, during the practice lifecycle (in mediantes), or ex-post (after implementation) when all the costs are sunk (Ng'ang'a et al., 2020). The main economic indicators for CBA under consideration in this study include the net present value<sup>3</sup> (NPV), the internal rate of return<sup>4</sup> (IRR), the Benefit-Cost Ratio (BCR), and the payback period<sup>5</sup> (PP). The profitability of the practices was assessed with incremental benefits which were measured by increased productivity (yield multiplied by the output price) compared to the BAU practice. The incremental costs were measured by multiplying the changes in the units of machinery, inputs, service, and labour used by their corresponding unit costs.

With a focus on five out of 16 countries with established Green Innovation Centres for the Agricultural and Food Sector (GICs), this study provides an assessment of climate-smart practices and innovations for selected value chains. Each country's focus was specific as the GICs often coordinate their activities with various governmental institutions, research, and private sector stakeholders within each country to tailor-make a bundle that will enable the smallholder farmers to increase their productivity and income. The five focus countries in this study were arbitrarily chosen to be representative of the Eastern, Southern, and West Africa Regions. The rest of the paper is organized as follows: in section 2 we introduce the study area, describe the data collection and analysis process, explain the prioritization of the climate-smart agriculture practices, and summarize how CBA analysis was applied. Section 3 presents the results and discussions and section 4 concludes and provides policy recommendations.

## 2. Methodology

### 2.1. Study areas

This study was focused on five SSA countries: Ethiopia, Kenya, Malawi, Nigeria, and Zambia. The agricultural value chains (Table 1) selected are those prioritized by the German Corporation for International Cooperation (GIZ). The GIZ project initiative of 'One World, no hunger' is implemented through Green Innovation Centres (GICs). These centres aim at improving the resilience of agricultural systems by promoting the uptake of innovations that increase productivity, improve water, food, and nutrition security.

Commissioned by the Federal Ministry of Economic Cooperation and Development (BMZ), a total of 16 GICs have been established across SSA, India, and Vietnam. Countries in SSA include Benin, Burkina Faso, Cameroon, Ivory Coast, Mali, Mozambique, Togo, and Tunisia. The selected value chains were restricted to those specific to the GIZ priorities in each country.

Kenya and Ethiopia are located in the East African region which is often characterized by a tropical climate. The mean annual temperatures

<sup>3</sup> NPV refers to the value of discounted future net benefits. If the NPV of the innovation is greater than zero, then it is acceptable.

<sup>4</sup> IRR refers to the discount rate that equates the NPV to zero. If the IRR is greater than the discount rate then the adaptation innovation is deemed desirable.

<sup>5</sup> PP refers to the time taken in years, for the costs of the innovation or practice to be completely paid off by the benefits realized.

<sup>1</sup> A planting pit of about two meters in diameter.

<sup>2</sup> A planting pit about 20–40 cm in diameter and 10–15 cm in depth.

**Table 1.** Study areas and the focus value chains.

Country	GIC Value Chain	Study Area
Kenya	Sweet Potato	Siaya, Bungoma, Kakamega, Nyandarua
Ethiopia	Faba Beans	Arsi region
Zambia	Soybeans and Peanut	Eastern and Southern Provinces
Malawi	Soybeans, Peanut, cassava	Central region
Nigeria	Potato, corn, cassava, Rice	Ogun, Oyo, Benue, Nassarawa, Kano, Kaduna, Plateau

GIC stands for Green Innovation Centres.

for Ethiopia are in the range of 15–20 °C and 20–30 °C in the high altitude and lowlands areas respectively. The temperature for Kenya is about 15 °C in the central highland regions which are cooler compared to the coastal lowland areas experiencing highs of 29 °C on average. Rainfall for the two countries ranges from 50mm to 350mm per month (Mcsweeney et al., 2010a, 2010b). In Kenya, the focus value chain was sweet potatoes (*Ipomoea batatas*) while in Ethiopia, the focus was on faba or broad beans (*Vicia faba*).

Malawi and Zambia are located in the eastern and central regions of southern Africa respectively with both experiencing a tropical climate. Mean temperatures for Malawi range from 18–19 °C to 22–27 °C in the winter and summer seasons respectively. In Zambia, winter temperatures range from 15–20 °C and between 22–27 °C in the warm seasons. Rainfall for both countries ranges between 150–300 mm per month during the wet seasons (Mcsweeney et al., 2010c, 2010d). Soybean (*Glycine max*), peanut (*Arachis hypogaea*), and cassava (*Manihot esculenta*) were the focus value chains in Malawi while peanut, soybean, and milk were the focus in Zambia.

Nigeria is located in the West African region, characterized by a climate mosaic ranging from tropical and semi-tropical to semi-arid in the northern regions. The climate is highly influenced by the interaction of the Inter-tropical Convergence Zone (ITCZ) and the West African Monsoon or the Harmattan winds (Karmalkar et al., 2010; Barry et al., 2018). The rainfall variability is highly influenced by the timing and the intensities of the ITCZ which is also caused by the *El Niño* Southern oscillations. These result in climate shocks in the region and coupled with anthropogenic activities, present challenges in achieving sustainable development, especially for the countries highly dependent on rain-fed agriculture. For Nigeria, the focus value chain was rice (*Oryza sativa*), maize (*Zea mays*), potato (*Solanum tuberosum*), and cassava (*Manihot esculenta*). However, for the CBA calculations, we focused on a few selected value chains in each country for specific prioritized CSA practices.

## 2.2. Data collection and analysis process

The data collection process involved several steps. In the first step, the value chains under consideration were based on the selected GIC value chains in the focus countries (Table 1). With the value chains predetermined, the second step involved conducting an online survey with key informants along each value chain to help in the evaluation of the current innovations. The third step involved conducting an in-depth and systematic review of the literature to supplement the information obtained from the online survey of the innovations implemented by smallholder farmers. The online surveys were administered to smallholder farmers within each value chain with tracing of the respondents being guided and led by stakeholders within the GICs. The questionnaires were sent via email with follow-up done through phone calls and Skype meetings whenever it was applicable.

The fourth step was the prioritization process which involved a ranking process whereby key factors were used to rank the main adaptation practice. These included ease of implementation, economic profitability, costs, value for money, the time before realizing benefits, ease of

use, or ease of scale. The factors chosen were context-specific and depended on climate hazards and the value chain under consideration. Stakeholders chose at least 10 innovations that helped farmers improve their resilience and productivity. They then selected the two most promising practices at each stage of the value chain (input supply, on-farm, post-harvest, and marketing stage). Each adaptation option was then ranked based on its importance in increasing productivity on a scale of one to eight where a score of one indicated high importance and eight, low importance. For a value chain with five practices then the score ranged from one to five.

The final step involved conducting another online survey with at least five key resource persons (selected smallholder farmers who have adopted at least one of the prioritized innovations) to estimate the costs (implementation, maintenance, and operations costs) and the benefits (increased yields and output prices) for each prioritized innovation both as they relate to the BAU case and the adoption of the prioritized innovation. The first phase of interviews was aimed at identifying the current CSA practices and evaluating the prioritized ones based on the selected criteria (CSA-PF). This provided a broad overview of the practices. The second phase of the online interviews focused on estimating the cost and benefits of the prioritized practices.

The internet has proven to be an important domain for conducting surveys research especially for targeting virtual communities. Thousands of individuals, groups, and organizations especially in SSA are gradually embracing the use of technology in their operations. In the context of this study, data was collected within the first and second quarters of 2020, a period when most countries around the world were under lockdown and strict travel restrictions due to the emergence and rapid spread of the COVID-19 pandemic. The use of online surveys, though with the disadvantage of having sampling issues and lower response rates, especially in the agricultural sector where most researchers often rely on face-to-face contact with the farmer or farmer groups presented an opportunity that enabled access to relevant information from key informants at a lower cost and within a shorter period.

Upadhyay and Lipkovich (2020) opined that the use of online interviews could help achieve a diverse sample of participants. With the current status of the COVID-19 pandemic, it is becoming increasingly urgent to refine the use of remote research methods. Although using online interviews is a marginalized method for data collection, it has the potential of eliminating time and space boundaries, reducing research costs, and encouraging an iterative reflection where both the participant and researcher can keenly reflect on the questions and provide thoughtful answers (Bowden and Galindo-gonzalez, 2015). To overcome the limitations associated with online interviews, the participants were actively engaged with the help of GIC experts in each region and were informed before to build a good rapport. The participants were also informed of the project time frame and reminders were sent about answering the interview questions.

This study used both secondary and primary data. The primary data was obtained from the online survey and key informant interviews. The secondary data was collected from reviews of relevant published literature from national and government ministries, research institutions, and Non-Governmental Organisations NGOs in the five study countries. Both qualitative and quantitative techniques were used to analyze the data collected. The data and information from the online survey and interviews were entered directly into a CBA excel tool and STATA software was used for analysis (StataCorp, 2019). To ensure the reliability of the data, the study compared its findings with other similar past studies done across countries in the SSA region. This allowed checking for consistency and whether the study results can be reproduced under the same conditions. The household was used as the unit of analysis for comparing the profitability with and without the CSA practices. Estimates of the net benefits, cost-benefit ratios, and the rate of return were evaluated against the averages from the BAU practices in each year. The methodologies applied in this study are conventional and can be applied in different contexts.

### 2.3. Prioritizing climate-smart agricultural practices

The CSA-PF tool developed by the International Centre for Tropical Agriculture (CIAT) and the CGIAR research program on Climate Change, Agriculture, and Food Security (CCAFS) was applied (Figure 1) in this study. CSA-PF provides an elaborate step-by-step process that helps stakeholders narrow down a long list of Climate-Smart Agriculture (CSA) practices to a short portfolio of viable options.

The first step involved identifying both the ongoing and promising practices related to the scope and stage of the value chain. The second step included selecting the two most promising practices at each step of the value chain (input purchase, production, post-harvest, and marketing). This was dependent on a selected criterion, for instance, the severity of climate hazards such as floods or droughts. The third stage was the ranking of the selected CSA practices by order of importance. The criteria for the selection included the practice lifecycle, impact on productivity, building resilience, and mitigation benefits. Finally, a comprehensive CBA was conducted to evaluate the economic viability of the prioritized CSA practices. The aim was to achieve economic efficiency and provide reliable information for value chain stakeholders to make rational decisions. For a detailed explanation, please see (Sogoba et al., 2016; Andrieu et al., 2017; Sain et al., 2017).

Spearman's rank-order correlation was computed to determine the relationship in the ranking of the innovations based on the climate hazards for each value chain Eq. (1).

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (1)$$

Where  $\rho$  is Spearman's correlation coefficient,  $d$  is the difference between the ranks in each observation, and  $n$  is the number of observations. The null hypothesis tested was that there is no significant difference between the ranks,  $\rho = 0$ , and the counterfactual in the relevant indicating that there is a relationship between the ranks  $\rho \neq 0$ . In Spearman's correlation coefficient, the  $\rho$  can take values from +1 to -1. A  $\rho$  of +1 indicates a perfect association of ranks,  $\rho$  of zero indicates no association and of -1 indicates a negative association of the ranks. The closer the rho is to zero the weaker the association between the ranks.

### 2.4. CBA methodology

Four decision criteria are used under CBA. These are NPV, IRR, benefit-cost ratio, and PP. The NPV is the value of the discounted future net benefits (Eq.2). A project or adaptation practice with an  $NPV > 0$  is deemed viable and should therefore be adopted. A project is rejected if otherwise (i.e.,  $NPV < 0$ ).

$$NPV(B, C) = \sum_{t=0}^T \frac{B_t}{(1+r)^t} - \sum_{t=0}^T \frac{C_t}{(1+r)^t} \quad (2)$$

Where  $T$  represents the lifecycle of the adaptation practice,  $B$  represents the benefits,  $C$  represents the costs, and  $r$  is the relevant discount rate. In this study, we compared the changes in cost and benefits of the prioritized CSA practice compared to the BAU practice. The incremental benefits were evaluated in terms of the positive change in yield multiplied by the price of the commodity in the specified value chains. The incremental costs were evaluated as the changes in quantities used for inputs, services, labour and machinery, and equipment as they relate to the implementation, maintenance, and operations costs multiplied by their respective unit costs. Breaking down Eq. (1) to represent these changes is represented by Eq. (3) which is customized from (Ng'ang'a et al., 2017).

$$NPV_j^{INV-BAU} = \sum_{t=1}^T \frac{1}{(1+r)^t} \left[ \sum_j P_{jt} \times \Delta Y^{INV-BAU} - \sum_{j=1}^j C_n \times \Delta Q_{jt}^{INV-BAU} \right] \quad (3)$$

Where  $P_{jt}$  is the per-unit price of the commodity  $j$  in time  $t$  and was assumed to be constant,  $\Delta Y$  in the annual change in yield of commodity  $j$  between the BAU practice and the innovation,  $C_n$  represents the per-unit cost for the inputs/machinery/services/labour and was also assumed to be constant,  $\Delta Q_{jt}^{INV-BAU}$  is the annual change in the units of inputs/machinery/labour/services used for the innovation compared to the BAU,  $r$  is the discount rate and  $T$  represents the lifecycle of the innovation. The second decision criteria under CBA are the IRR and the B/C ratio tests.

The IRR is an approach that calculates the discount rate which gives the project an NPV of zero and then compares this with the pre-determined discount rate given by Eq. (4).

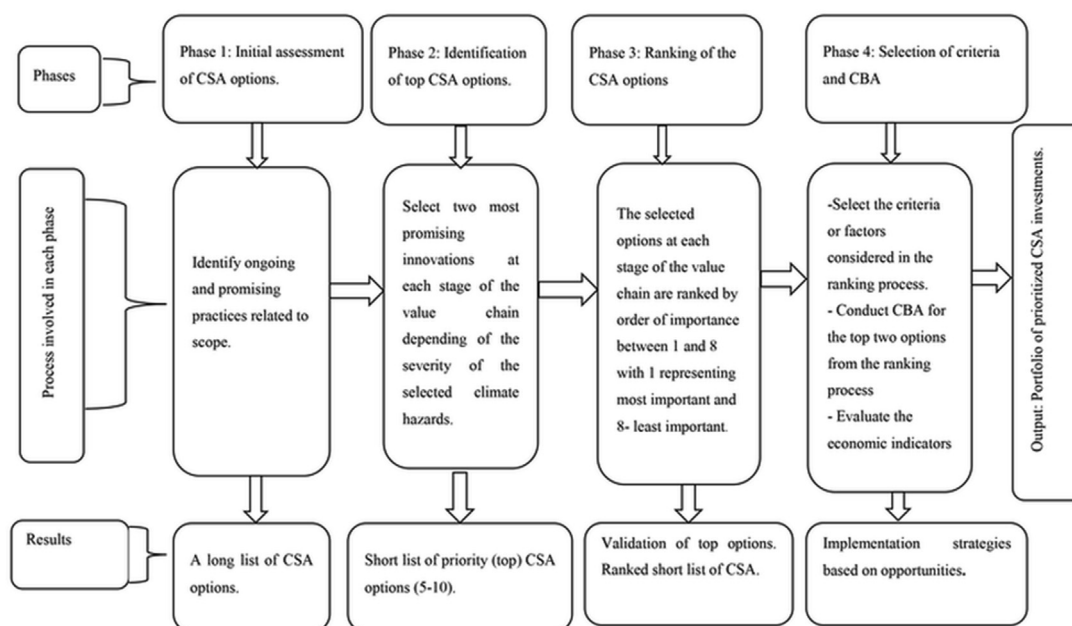


Figure 1. Climate Smart Agriculture Prioritization framework (CSA-PF). CSA stands for Climate smart agriculture, CBA represents Cost-Benefit Analysis.

$$B_0 - C_0 + \frac{B_1 - C_1}{(1+i)^1} + \frac{B_2 - C_2}{(1+i)^2} + \dots + \frac{B_T - C_T}{(1+i)^T} = 0 \quad (4)$$

Where  $i$ , represents the discount rate that solves the equation (IRR). The decision rule while considering the IRR is to consider implementing the innovation if the calculated IRR is more than the predetermined discount rate Eq. (5).

$$IRR > r \quad (5)$$

The B/C ratio test is given by Eq. (6).

$$B/C = \frac{\sum_{t=0}^T \frac{B_t}{(1+r)^t}}{\sum_{t=0}^T \frac{C_t}{(1+r)^t}} \quad (6)$$

The decision rule, in this case, is similar to that of NPV where a policy action or project is deemed worthwhile if the ratio is positive and greater than 1. This implies that the benefits realized from adopting the adaptation strategy can completely offset the costs incurred with some residual benefits.

Calculation of the payback period is a simplified way of evaluating the risk associated with investing in agricultural innovation. It represents the time required for the total amount invested to be repaid by the net cash flow generated (Mutenje et al., 2019). The payback period is represented by Eq. (7).

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Net cashflow period}} \quad (7)$$

Table 2 describes the main variables used in CBA. Thus, the different cost components and variables are used in estimating the benefits.

### 2.5. Sensitivity analysis

Sensitivity analysis illustrates the effect that a change in a variable has on the NPV. The treatment of uncertainty is very critical in any CBA study and especially when dealing with the subject of climate change. The study applied the pessimistic-optimistic scenario and the switching value methodologies in conducting the sensitivity analysis. The optimistic scenario assigns the most favorable values to the variables while the pessimistic scenario assigns the least favorable values (Commonwealth of Australia, 2006). Five variables were considered in the analysis: price per bag of output, yield per hectare, annual labour cost, discount rate, and the practice life cycle. With the assumption of a perfect market, a 10% change in the variables was arbitrarily chosen. The pessimistic scenario included a 10% increase in the annual labour cost and the discount rates and a 10% decrease in price per bag of output, the yield per hectare, and the practice lifecycle. The contrary was applied in the optimistic scenario. The responsiveness of the NPV to changes in any one of the variables was conducted *ceteris paribus* (thus keeping the others constant while changing one variable at a time).

The switching values methodology was also applied to justify the results obtained from the optimistic and pessimistic scenario analysis. In the switching values, one variable was changed, *ceteris paribus*, until a value that gave an NPV of zero was obtained. The difference between the base value and the switching value was obtained to evaluate which variable to which the NPV was least/most sensitive.

## 3. Results and discussion

The use of the CSA-PF consecutively with the CBA tool allows for the proper identification of best-bet CSA options. Considering the opinions of all stakeholders along the value chains through the prioritization process provides key insights on how to properly implement adaptation at the farm level. The study also gives comprehensive CBA results considering not only the net present value and the internal rate of return as conventionally used but also shows the payback period, the benefit-cost

Table 2. Variables used in CBA.

Item	Description
<b>COSTS:</b>	
Implementation costs	Includes the costs incurred at the beginning of implementing the practice (once-off costs and every year or every season).
Maintenance costs	Costs that are incurred every year or per season depending on the crop but exclude the one-off costs
Operational costs	Costs that deal exclusively with the harvest threshing, labour for harvesting, machinery used for harvesting, storage facilities
Machinery and equipment	Includes all the machinery, tools, and equipment used at the beginning of the practices (panga, wheelbarrow, ox plough, hoe, rope, spraying machine)
Inputs	Includes for example costs of seeds, fertilizers, pesticides, storage bags.
Services	Includes, for example, greasing of equipment, transportation costs, sharpening of tools
Labour	Land preparation, land opening, fertilizer application, sowing, weeding, threshing, harvesting. The labour costs were measured in man-days with the increase or decrease estimated by the difference between the labour used under farmer practice and the CSA practice. The difference was multiplied by the estimated market prices for labour per man-day. A decrease in the labour costs is favorable as this is indicative that the CSA practice allows the farmer to minimize their operational costs.
<b>Benefits:</b>	
Increased yield	Increased yield/output from implementing the innovation. (Kgs/ltrs) compared to the BAU
Discount rate:	The current commercial bank interest rate on investment loans (%)
CSA lifecycle	The period in years from when the farmer implements the CSA practice to when he/she stops or implements a new practice.
Price of outputs (Y)	Evaluated using current market prices of the specific product (US\$ per unit)
Price of Inputs	Evaluated using current market prices of specific inputs used (US\$ per ha)

Note: Kgs- Kilograms, US\$- United States Dollars, HA-hectares, yrs- years, ltrs- Litres, BAU- Business As Usual.

ratios, and sensitivity analysis. These allow for risk assessments using scenario analysis given that climate and markets are dynamic. Evaluating the different value chains across the selected five SSA countries is useful for making comparisons since the different regions have varied climate profiles, and the crops are affected by climate change risks at varying degrees. For instance, the climate of the East African countries (Ethiopia and Kenya) varies from arid, semi-arid to tropical in different AEZ. The West African region has a hot semi-arid climate that is characterized by very high temperatures all year round. We first provide results for the most prioritized innovations among smallholder farmers and their standard ranks, followed by results on the CBA indicators, finally, we provide a synthesis from the literature on externalities that result from the CSA strategies.

### 3.1. Prioritized innovations among smallholders in the selected value chains

The use of improved seed variety was highly prioritized in all the study areas (Table 3). The adoption of improved seed varieties, in the context of this study, includes varieties that are tolerant to climate risks such as drought and floods. The plausible reason is that they reduce the risks of crop failure or yield losses (FAO, 2010). The use of improved seed variety was most applicable during extreme climate events such as prolonged drought, late onset of rainfall, or long flood periods. In the long run, this ensures household income is stabilized, household food and nutrition security are enhanced due to the all-year-round food supply.

Improved seed varieties for sweet potato have been proven to be highly nutritious containing essential minerals and vitamins for proper

**Table 3.** Standard rank of the most prioritized innovations.

Country	Value chain	Innovation	Standard Rank
Kenya	Sweet Potato	GAP	1
		New/improved seed varieties	2
Nigeria	Milk	Commercial fodder production	1
	Potato	New/improved seed varieties	3
Malawi	Rice	GAP	1
	Cassava	New/improved seed varieties	4
Zambia	Soybeans	Conservation agriculture	2
		New/improved seed varieties	1
		Conservation agriculture	3
Ethiopia	Faba beans	New/improved seed varieties	3
		Commercial fodder production	1

Note: GAP stands for Good Agricultural Practices. The results are the output of stages 1–3 of the CSA-PF.

human growth and development, especially in infants (Kaguongo et al., 2012). For instance, sweet potato tubers contain proteins, carbohydrates, fiber, energy, vitamins A, B1, B2, B3, B6, C, E, and minerals such as Calcium, Phosphorous, Folate, Magnesium, Iron, Potassium, and Zinc. The yellow and orange-fleshed roots also provide pro-vitamin A (Makini et al., 2018).

The other two most prioritized innovations among smallholder farmers in all the study areas were the application of GAP at all stages of the value chain and conservation agriculture. GAP is taken here to mean activities done at the pre-harvesting and post-harvesting stages. Examples include weeding, alternate wetting and drying in rice cultivation, selecting proper harvesting dates, proper storage bags during harvest, proper management of storage facilities, among others. The conservation agricultural practices include minimum tillage, mulching, and crop rotation or intercropping.

The main evaluation criteria for prioritization were on the importance of innovation in increasing productivity, building resilience against climate change risks, and mitigation. Innovations that had ranks between 1 and 4 were selected (Table 3). A rank of 1 indicates that the innovation is deemed to be very important. A Spearman's correlation was run to assess the relationship between the ranks of the strategies at each stage of the value chain (Table 4). All the ranks were independent of each other.

The correlation coefficients indicate that there was a negative insignificant relationship between the ranks for the 153 respondents,  $r_s = -0.111$ ,  $p = 0.05$ . This implies that the ranking of the strategies in each stage does not influence each other. Plausible reasons could be because the impact of each innovation was stage-specific. For instance, at the input stage, smallholder farmers considered the application of fertilizer to be very important for stable and improved productivity. At the farm production stage, a practice such as the use of clean seeds, mulching, or minimum tillage practice was ranked as very important. At the post-harvest and/or the marketing stage strategies such as strengthening of cooperatives and farmers groups were deemed important.

The prioritization of climate-smart innovations is imperative as it allows for better adaptation planning. Dogulu and Kentel (2015) identified additional criteria used for prioritization such as the costs, benefits,

effectiveness, sustainability, time spent for planning and implementation, flexibility, social acceptance, equitability among others. In a study conducted in the Bihar district of South Asia, Shirsath et al. (2017) used the three criteria for climate smartness (productivity, resilience, and mitigation) to identify the most prioritized practices for different future climate scenarios. The prioritized innovations from the study included the use of GAPs such as alternate wetting drying in rice cultivation, index-based insurance, conservation practices such as reduced tillage, and farm-level water management. The application of different frameworks and methodologies in the prioritization of climate adaptation strategies allows for diversity in portfolio development and management (Mwongera et al., 2017; Khatri-Chhetri et al., 2017; Shirsath et al., 2017).

### 3.2. Cost-benefit analysis of prioritized innovations for selected value chains in the SSA countries

CBA was computed for three innovations; GAP, improved seed varieties, and conservation agriculture for selected value chains (Table 3). The main indicators under consideration included the discount rate, the NPV presented in US\$, the IRR, the B/C ratio, the practice life cycle, and the payback period. The results indicate the profitability and viability of all the prioritized climate adaptation practices in all the selected five countries (Table 5). The discount rate used in most countries was 10% except for Malawi and Ethiopia where the discount rates were 13.5% and 12% respectively. This is because the rate used was similar to the interest rates used by banks in advancing investment loans which vary across countries. The payback period, which is the time it takes for the practice to fully repay its initial capital, varied between one and two years for most of the practices (Table 5). This indicates acceptability among smallholder farmers since the shorter periods allow them to repay any credit advanced to them and at the same time enjoy the profits from the investment.

The lifecycle period for the prioritized innovations ranged from 5 to 20 years. Adoption of improved seed varieties had the minimum lifecycle of 5 years while CA for the peanut value chain in Zambia had the maximum life cycle of 20 years. However, the lifecycle is value-chain and country-specific given that CA for the soybean value chain in Malawi had a lifecycle of 5 years. The costs used in the CBA calculations were those analogous with the implementation, maintenance, and operational activities of the CSA practice based on 1 ha for 1 year. The prices of the inputs and outputs were constant.

#### 3.2.1. Private profitability

The CBA analysis in this study examined farm activities that were affected by the CSA within the specified value chain in each of the five studied countries. Evaluation of the costs and benefits considered the effect of the practice on one hectare of land as the unit of analysis. The data on the BAU considered input and output values before the implementation of the CSA practice and was based on recall data as well as information from key informants in each country. The estimation did not account for sunk costs, fixed costs such as land value, interest on capital, or depreciation value.

All the practices had a positive NPV meaning that all were deemed worthwhile. GAP in the sweet potato value chain in Kenya had the highest NPV (US\$ 28,044) while CA in the soybean value chain in Malawi had the lowest NPV (US\$ 508). The NPV values for the other

**Table 4.** Spearman's rank correlation coefficients.

Variables	Promising Rank_1	Promising Rank_2	Promising Rank_3	Promising Rank_4
Promising Rank_1	1.000			
Promising Rank_2	-0.087	1.000		
Promising Rank_3	-0.414	-0.232	1.000	
Promising Rank_4	-0.282	-0.276	-0.111	1.000

Spearman rho = -0.111.

**Table 5.** CBA of prioritized innovations in 5 SSA countries.

Country	VC	Practice	Probability distribution average					
			r (%)	NPV (US\$)	IRR (%)	B/C	T (Yrs)	PP (Yrs)
Kenya	Sweet potato	Improved seed	10	8,738	111	2	10	2
		GAP	10	28,044	328	4	10	1
Nigeria	Potato	Improved seed	10	6,301	196	2.5	5	2
	Rice	GAP	10	2,182	148	4	10	2
Malawi	Soybeans	Improved seed	13.5	1,001	489	6	5	1
		CA	13.5	508	493	13.7	5	1
	Cassava	Improved seed	13.5	8,976	309	3.6	5	1
Zambia	Peanut	CA	10	2,796	368	14.6	20	1
	Soybeans	Improved seed	10	1,563	252	3	10	1
Ethiopia	Faba beans	Improved seed	12	2,366	175	2.4	5	2

NB: r = discount rate at which the NPV has been discounted, IRR = internal rate of return, T = practice life cycle, PP = practice payback period, GAP-Good Agricultural Practices, CA-Conservation Agriculture.

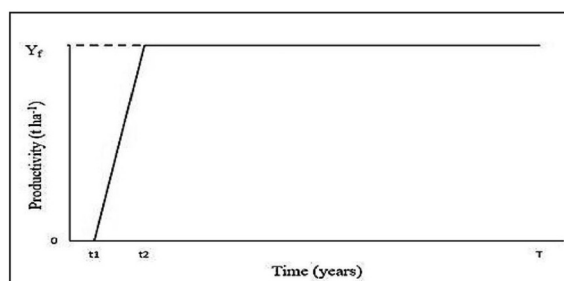
practices ranged between US\$ 1,000 to US\$ 8,900 (Table 5). The results of the IRR also indicated that all the practices were profitable since they were all greater than the corresponding discount rate. Improved seed varieties in the sweet potato value had the lowest IRR (111%) while CA in the soybean value chain in Malawi had the highest IRR (493%). The difference in the IRR between the two practices could be attributed to the varying cash flow patterns given that conservation agriculture within the same value chain presented the lowest NPV (US\$508) (Table 5). CA, for instance, had a very low initial capital investment (US\$26). The incremental cost flows for the subsequent years were all negative (US\$ -7) in comparison to improved seed variety in the sweet potato value chain where the initial capital investment was estimated at US\$ 1,619 and the cash outflow for the subsequent years were all positive (US\$ 1, 424).

The benefit-cost ratios for all the practices were greater than 1. A clear indication that the benefits realized for each practice can fully cover the costs associated. CA in the peanut value chain in Zambia had the highest B/C ratio of 15 while the lowest B/C ratio of 2 was realized in the improved seed in the sweet potato value chain in Kenya. This is despite the differing values of their NPV (US\$ 2,796 and US\$ 8,738) respectively.

The results from this study resonate with those obtained by (Mutenje et al., 2019) in a study conducted in the Southern African countries of Mozambique, Zambia, and Malawi. In the study, a combination of CSA practices adopted by farmers in Mozambique: CA tillage, improved maize varieties, soybean rotation, and relay cropping using common bean yielded an NPV of US\$2442.49 and IRR of 489%. In Zambia, a combination of CA, drought-tolerant maize, and soybean rotation yielded a profitability NPV value of US\$1866.01 and an IRR of 529%. The study noted that the success of any CSA practice was context-specific and significantly influenced by the micro-climate, labor, and the CSA combination implemented.

In the CBA profitability indicators discussed (NPV, IRR, and B/C ratio), NPV was found to be the most appropriate measure to show whether a practice is worthwhile or not. The IRR and the B/C ratio are applicable where there is only one alternative under consideration while the NPV is very useful where there is more than one alternative to choose from (Branca, 2018). The use of the IRR as a profitability indicator may sometimes yield unreasonable values that might be challenging to interpret for quantitative purposes. The very high IRR values obtained in each practice (Table 5) imply that lesser value will be attached to future cash flows associated with the CSA practice than it ought to be. As such, the NPV is often considered as the best profitability measure as opposed to the IRR.

The response curve (Figure 2) that illustrates the yield pattern associated with the implementation of the CSA practice takes on the shape of a Liebig production function (Sain et al., 2017). It follows a linear plateau preceded by a time lag demonstrated by the difference in yield between t1 and t2.



**Figure 2.** The proposed shape of the productivity response function (Adapted from Sain et al., 2017) (The productivity increases exponentially from t1 to t2 given one limiting factor and then stabilizes over time when other factors limit production).

The time lag represents the period between when the CSA practice is being implemented (t0) to when there is a change in yield due to the implementation of the practice (t1).  $Y_f$  represents the maximum yield increase associated with the practice. After  $Y_f$  the physical response reaches a linear plateau (t2 to T). T represents the entire lifecycle of the practice. The y-axis measures productivity in tonnes per hectare while the x-axis measures the time in years. The concept behind the Liebig production function is that at any moment there is only one factor, said to be in minimum supply, which limits production. For instance, the level of nitrogen (N) in the soil. If the supply is increased through the use of fertilizer rich in N, then production will increase proportionally up to a point where a second factor now limits production (Williams et al., 2020). For example, water availability. As illustrated in Figure 2, there is an abrupt transition from one limiting factor to another.

### 3.2.2. Externalities

All climate adaptation strategies generate externalities. They may be positive or negative. In the context of this study, externalities refer to the social and environmental costs and benefits. Although the scope was limited to only the private profitability, information was sourced from various literature that discussed the externalities associated with adopting climate change adaptation strategies. The externalities include the effect on crop and soil biodiversity, air quality, water availability, soil erosion, and social impact which is evaluated as an increase/decrease in labour requirement.

To evaluate the effect on biodiversity, Sain et al. (2017) applied a biodiversity index developed by The Tropical Agricultural Research and Higher Education Centre (CATIE). A biodiversity index of 0.64 was obtained. This value was then multiplied by the shadow price of biodiversity to estimate the impact. The shadow price was used as a proxy for the market price to indicate the value the society is willing to pay or the value

they are willing to receive for an extra unit of the externality. The closer the biodiversity index is to one ( $>0.5$ ) the more diverse the ecosystem is. Thus, in this case, presenting positive externalities. A biodiversity index is used to estimate the complexity, stability, and general health of an ecosystem. It is calculated by dividing the number of species in an area by the total number of individuals in the area. Thus the closer the index is to 1 the more diverse the ecosystem.

Williams et al. (2020) used soil fertility as a proxy for soil and crop biodiversity. In this case, an increase in soil fertility increased plant species per unit area thus increase in crop biodiversity. The use of organic manure to increase soil fertility resulted in improvement in below-ground soil activity. In estimating the effect on biodiversity, the soil fertility per hectare was estimated by the product of the change in N gained by the shadow price. Ng'ang'a et al. (2017) applied the Monte Carlo Simulation and estimated the value of increased biodiversity from implementing CSA practice to be approximately USD 22 ha<sup>-1</sup> year<sup>-1</sup>. According to Ng'ang'a, 2017, the estimated value of the carbon sequestered and reduction of air contamination by the adoption of agroforestry practice over the entire lifecycle is equal to US\$700 and US\$ 670 ha<sup>-1</sup> yr<sup>-1</sup> respectively.

Climate change poses a challenge for communities to attain air quality standards that affect the environment and pose risks to human health. To estimate the effect of climate adaptation strategies on air quality (reduced GHG emissions/increased carbon sequestration), valuation is universally done through the use of the global market price of carbon USD 6.00 t<sup>-1</sup>CO<sub>2e</sub> (Sain et al., 2017). This allows estimation of the level of carbon sequestered by the practice. For a case study in Ghana, Ng'ang'a et al. (2017) estimated this value at about USD 15 ha<sup>-1</sup> year<sup>-1</sup>. This means that the adoption of practices such as mulching, agroforestry, minimum tillage help minimize GHG emission thus improving air quality.

Improved water quality translates to water available for agricultural production, household use such as cooking and cleaning, and increased fish species in the rivers that can be sourced for food and sold for income. Improved water quality also interprets to reduced soil erosion and agrochemical residues in rivers and streams. The valuation is done by using opportunity costs. Water quality improvements associated with agroforestry systems such as hedgerows were estimated at a total of USD 514 depending on the area covered. Conservation tillage with mulch was valued at USD 90 (Sain et al., 2017). CSA practices have the potential for improving the environment and rural livelihood.

Table 6 presents the social impact or externality of adopting the CSA strategies evaluated by the effect on change in labour requirement. In this case, survey data collected for the CBA was used in the assessment with the assumption that the implementation and maintenance of the CSA in the five countries for the selected value chains required the use of additional labour. The change in the labour requirement was then multiplied by the corresponding market price of labour which was country-specific to obtain the change in the value of labour (Table 6). High labour requirements for the CSA practices were applied during the harvesting and threshing. In resource-constrained households, the high demand was supplemented by family labour which presents a trade-off against engaging in other off-farm activities.

CSA strategies that require the use of additional labour translate to additional employment for the vulnerable population, especially the youth and women. Although it may present a welfare loss to the farmer due to added costs, the ability of the practice to create employment means a welfare gain to society. The strategies that present negative values mean that less labour was required as compared to the BAU practice (Table 6). This implied a welfare gain to the farmer due to reduced labour costs but also a loss to society due to fewer employment opportunities.

The results of strategies presenting negative values are contrary to findings in most literature where all of the strategies evaluated have positive impacts on the value of labour (Sain et al., 2017; Ng'ang'a et al., 2017; Williams et al., 2020). CSA practices that gave the highest

**Table 6.** Estimated impact on labour due to adoption of CSA practice.

Country	Value Chain	Adaptation Practice	Change in labour requirement (Man-days/season)	Price of labour (USD MD <sup>-1</sup> )	Change in value of labour (USD)
Kenya	Sweet potato	Improved seed	277	2.83	784
		GAP	83	2.83	235
Nigeria	Potato	Improved seed	N/A	1.28	N/A
	Rice	GAP	-61	1.28	-78
Malawi	Soybeans	Improved seed	-49	1.03	-50
		CA	-49	1.03	-50
	Cassava	Improved seed	50	7.53	377
Zambia	Peanut	CA	-32	1.24	-40
	Soybeans	Improved seed	N/A	2.30	N/A
Ethiopia	Faba beans	Improved seed	31	2.73	85

N/B: MD represents man-days, GAP stands for Good Agricultural Practices, CA stands for Conservation Agriculture, USD stands for United States Dollars.

profitability (higher NPV) were also less labor-intensive. For example, in comparing the CSA practices in the sweet potato value chain in Kenya, GAP which had a higher NPV (US\$ 28,044) compared to improved seed (US\$ 8,738) also exhibited less labour requirement (83MD compared to 277 MD). This implies that it is worth implementing GAP in terms of financial and resource use efficiency. Similar findings were obtained by (Mutenje et al., 2019).

### 3.2.3. Sensitivity analysis

In the climate change adaptation discipline, sensitivity analysis is quite different from the basic analysis since it is based on scenario analysis (Table 7). In the case of drought-tolerant sweet potato seed varieties in Kenya, at a discount rate of 10% and a lifecycle of 10 years, the NPV was estimated at US\$ 8,738 and the IRR at 111%. The practice also increased the value of labour to about US\$ 784 (Figure 3a).

Figure 3a depicts the sensitivity of the NPV to changes in the different variables.

The results indicate that the NPV was least sensitive to changes in annual labour costs and discount rates as evidenced by the very high IRR. Results from applying the switching values method in the sweet potatoes value chain verified these findings (Table 8). More detailed results of the sensitivity analysis have been provided as supplementary material.

The switching value is the value of the variable under consideration that will give a negative NPV or zero (Table 8). Results show that NPV was most sensitive to any small changes in the yield variable compared to the other variables as evidenced by the small difference between the base value and switching value. The least sensitive variable was the annual labour cost as seen by the huge difference. In some cases, such as the

**Table 7.** Sensitivity analysis using the pessimistic-optimistic scenarios approach.

Item	Base	10% lower	10% higher	NPV (US\$)	
				Pess	Opt
Price per bag	600	540	660	7,447	10,029
Yield per hectare	594.06	534.65	653.47	6,801	10,574
Annual labour cost	300	270	330	8,200	9,276
Discount rate	10%	9%	11%	9,162	8,336
Lifecycle (Yrs)	10	9	11	7,975	9,431

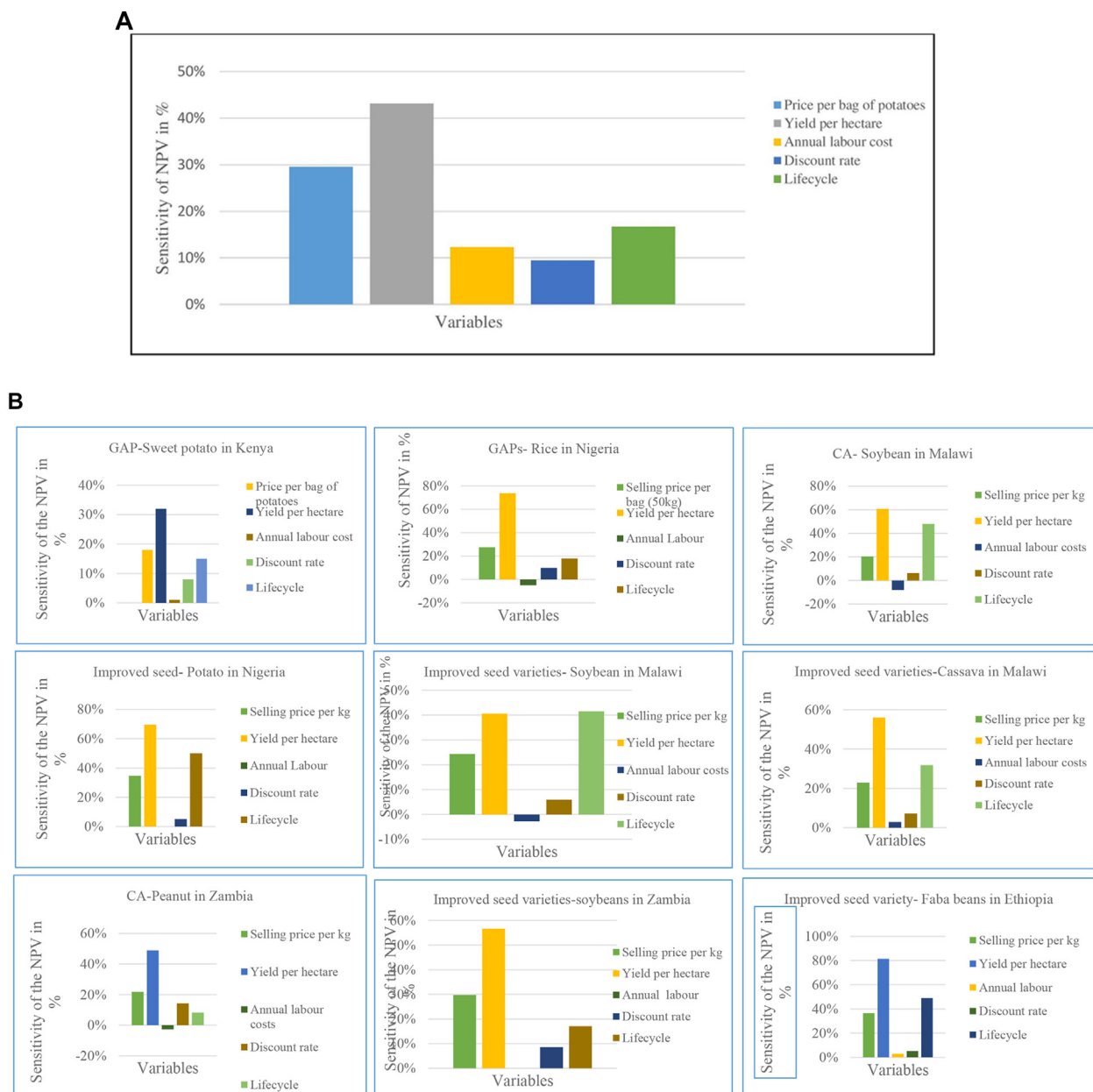
NB: Pess represents pessimistic and Opt represents Optimistic, NPV is the Net Present Value and US\$ stands for United States Dollars.

improved seed varieties in the potato value chain in Nigeria and soybean in Zambia, the labour presented no value (low or high) that could give an NPV of zero. Changing one variable at a time helps to assess how risky the project is and which variables significantly affect the NPV. It also helps to determine variables that are crucial to the robustness of the NPV. For example, if varying a variable like a yield has a large effect on the NPV, then the uncertainty about its value now and in the future becomes important. The policy should therefore be developed and implemented to ensure yield growth and stability.

Each bar represented in Figures 3a and 3b indicates a percentage change in value per hectare of the corresponding variable. A change in the discount rate resulted in a decrease of the NPV to US\$ (5,616). These are also replicable in all the value chains with different variations in the values (Figure 3b). The findings imply that with higher discount rates,

low yield, and lower prices, the profitability for all the practices will be lower. In contrast, profitability will be higher if we consider lower discount rates and lower annual labour costs.

There is an ongoing debate on the choice of the optimal discount rate to be used in climate change adaptation. Some scientists have proposed the use of lower discount rates based on environmental protection and sustainability (Agrawala et al., 2011; Sterner and Coria, 2012; Callaway et al., 2016). The proposed discount rates could be in the range of one and five per cent. Other scientists argue that very low discount rates may lead to misallocation of private resources and a misguided value of future benefits of a project (Mendelsohn, 2012). For public adaptation and future climate change to matter, the use of lower discount rates could be appropriate. This would favour a shift of policy decisions from adaptation to mitigation.



**Figure 3.** (a) Sensitivity of the net present value to changes in different variables (drought tolerant sweet potato varieties in Kenya). USD stands for United States Dollars, ha represents hectares. The bars to the right show a positive change in the NPV while the bars to the left represent a negative change in NPV given the two scenarios, optimistic and pessimistic. (b) Sensitivity of the net present value to changes in different variables (The rest of the value chains). USD stands for United States Dollars, ha represents hectares. The bars to the right show a positive change in the NPV while the bars to the left represent a negative change in NPV given the two scenarios, optimistic and pessimistic. In column two, on the second and third graphs, the writings on the y axis are not visible.

**Table 8.** Sensitivity of the NPV to different variables using switching values methodology.

Variables	Base value (1)	Switching value (2)	Difference (1–2)	IRR (%)
Price per bag	600	193.92	406.08	10
Yield per hectare	594	326.02	267.98	10
Annual labour costs	300	787.08	487.08	10
Discount rate	10	111	101	111
Practice lifecycle	10	2	8	10

Note: IRR = internal rate of return. The switching value is the value of the variable that gives an NPV of zero.

#### 4. Conclusion and policy recommendations

Several studies have evaluated prioritization processes within the climate change adaptation discipline, but few have comprehensively considered the costs versus the benefits (financial and economic) associated with the prioritized adaptation strategies. This study, therefore, goes further than the prioritization process. Two decision tools are applied for selected agriculture value chains in five SSA countries. The CSA-PF was first applied to identify the most prioritized CSA strategies based on a ranking of their importance in increasing productivity, resilience, and mitigation benefits. The study also employed the use of online interviews as the next frontier in conducting remote research. Having considered the current situation and rapid spread of the COVID-19 pandemic, the study leveraged the opportunity that presented a way of conducting a survey using available resources and at a shorter period. Agricultural research could take advantage of this to advance research and encourage the adoption of technologies such as mobile phones with internet access, especially among rural farmers.

A CBA tool developed by the International Centre for Tropical Agriculture (CIAT) was later used to evaluate the economic viability and efficiency of the prioritized CSA strategies. Economic indicators considered under CBA were the NPV, IRR, B/C ratio, and the payback period. Most smallholder farmers prioritized the adoption of improved seed varieties, conservation agriculture, and good agricultural practices. The CBA analysis revealed that the three are economically viable and if properly implemented at the farm level, could significantly impact agricultural productivity, income, and food security among households. The use of the CSA-PF consecutively with the CBA tool allows for the proper identification of best-bet CSA options. Considering the opinions of all stakeholders along the value chains through the prioritization process provides key insights on how to properly implement adaptation practices at the farm level. The study also gives comprehensive CBA results considering not only the net present value and the internal rate of return as conventionally used but also shows the payback period, the benefit-cost ratios, and sensitivity analysis. These allow for risk assessments using scenario analysis given that climate and markets are dynamic. Evaluating the different value chains across the selected five SSA countries is useful for making comparisons since the different regions have varied climate profiles, and the crops are affected by climate change risks at varying degrees.

Issues within the climate change discipline are interdisciplinary as adaptation strategies often require efforts of more than one sector. Cross-sectorial coordination needs to be recognized and fostered through suitable institutions for effective actions on adaptation strategies. In the context of this study, several policy recommendations are suggested. Considering the vulnerability of the agricultural sector, especially within the SSA region, to the negative effects of climate change, adaptation becomes the most relevant action to take. Appropriate prioritization for CSA practices is essential. Best-bet CSA options include those that can be implemented with the least cost, are highly effective, and are feasible both socially and technically.

Based on the criteria identified by value chain stakeholders, a list of prioritized CSA practices can be mapped out based on a scoring measure. For the selected value chains in the SSA countries identified for this study, the prioritized practices include the adoption of improved seed varieties, application of GAP, and conservation agriculture practices. A

CBA analysis of these strategies provides further clarity on their feasibility, especially at the farm level. Smallholder farmers who are financially and resource-constrained can make informed decisions in increasing their profitability. A solid identification and classification of various CSA alternatives are, therefore, necessary.

Institutions and governments should make available low cost-adaptation strategies as this could result in improvements in productivity and resource utilization. The private sector can support CSA innovations such as through the transfer of improved and climate-resilient seeds and conduct capacity building. The strengthening of these institutions through the development of property rights and encouraging participation will to a great extent encourage farmers to effectively adapt to a changing climate. This can further be enhanced through consulting experts and connecting stakeholders in all sectors, advocating for more coordinated approaches that allow for feedback, creating hubs for smallholder farmers that will help create ideal market dynamics. Through these institutions, constant provision of education to farmers can be enhanced to expand the knowledge base on the use of new adaptation technologies. In the process, new knowledge could also emerge on how best to improve the efficiency of the adaptation technologies already familiar among smallholder farmers in developing economies.

Adaptation strategies are context-specific. Thus, they could vary depending on the agricultural value chain under consideration and the country or focus region. Local-specific solutions and innovations should be developed to adapt to the local problems. For instance, the establishment of technologies such as seasonal weather forecast information can play a crucial role in guiding decision-making on climate change adaptation. The application of nexus sound solutions that contribute to optimal resource allocation and utilization could lead to increased economic growth and ensure environmental sustainability. For instance, planning strategies should first appraise the needs of all sectors and stakeholders as they relate to agriculture production, climate change adaptation, and mitigation. To ensure the sustainability of agricultural systems, interventions should aim at increasing agricultural productivity through climate-smart and resilient management practices through the choice of crop variety or cropping system.

#### Declarations

##### Author contribution statement

Devina Princess Akinyi: Analyzed and interpreted the data.  
Stanley Karanja Ng'ang'a: Conceived and designed the experiments.  
Margret Ngigi; Mary Mathenge; Evan Girvetz: Contributed reagents, materials, analysis tools or data.

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##### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

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