GLOBAL
CENTER ON
ADAPTATION

SUPPLEMENTARY PAPER SUPPORTING THE CHAPTERS ON MACROECONOMICS AND AGRICULTURE

STATE AND TRENDS IN ADAPTATION REPORT 2021: AFRICA

INTRODUCTION

Ahead of COP26, the Global Centre on Adaptation released its flagship **State and Trends in Adaptation Report 2021: Africa**. A major chapter in the report, **"The Macroeconomics of Adaptation,"** provided a deep dive into the economics of climate change impacts in Africa, presenting the findings of recent analyses on the potential economic costs of climate change, as well as recent evidence on the potential macroeconomic risks of climate change for the continent. Additionally, the chapter considers the potential economic benefits of adaptation and summarises the potential costs and benefits of adaptation interventions in Africa. Another major chapter in the report deals with **the prospects and possibilities for adaptation in agriculture and food systems, the mainstay of livelihoods in Africa**. It also attempts to provide a quantitative basis for the cost of action on various agricultural interventions in Africa to deal with climate change and, by comparing such costs against the (much larger) costs of inaction, to make a strong economic case for a rapid deployment of such interventions.

This paper provides the supporting information for these analyses and results reported in the main chapter. The first part, corresponding to the chapter on the macroeconomics of adaptation, presents supporting evidence for the synthesis of economic estimates presented, a detailed review of studies on the impacts of climate change on sovereign credits, and a review of the findings of the Benefit-Cost Ratios (BCRs) reported in Figure 4 of the main chapter. The second part, providing background material for the chapter on agriculture and food systems, presents an explication of the methodology used to make various complex calculations about the costs of action and inaction with respect to five areas of priority for agriculture in Africa.

THE ECONOMIC COSTS OF CLIMATE CHANGE IN AFRICA

Using an economic framework, it is possible—at least in theory—to estimate the economic costs of climate change globally and regionally. A small but established economic literature of global economic integrated assessment models (IAMs) have used such frameworks and assessed the economic costs of climate change (as reported in IPCC 2014,[1] Nordhaus and Moffat 2017[2]; Tol 2018[3] and Kahn et al. 2019[4]).These earlier IAM studies reported modest economic global impacts from climate change (without mitigation or adaptation), e.g. with a 1 to 2% welfare-equivalent income loss, expressed as a percentage of income, for 2–3°C of warming.

Many of these same IAMs estimate higher impacts in Africa. For example, analysis with the FUND model (AdaptCost 2009[5]) estimated that under a business as usual scenario, net economic costs could be equivalent to 2.7% of GDP each year in Africa even by 2025, but with higher costs in Sub-Saharan Africa (3.4%). The model reports large costs from water resources, health impacts, and energy costs for cooling, but some potential benefits from agriculture. The same study used the PAGE model and estimated costs at around 2% of GDP each year in Africa by 2040 (central value, market and non-market sectors, A2 scenario), with a 5–95% range of 0.4% to 4%.

These earlier IAM modeling results have been contested by some climate economists for several reasons. First, they exclude many impacts that are difficult to quantify or monetize (notably biodiversity and ecosystem services) and are thus underestimates of potential damages (Watkiss and Downing 2008[6]). Second, the functional relationships used in these models have been questioned, especially the extrapolation to higher temperature levels (Ackerman et al. 2009; Howard and Sterner 2014).[7] Third, there is also the potential for large-scale, non-linear global catastrophic events, called tipping points (Lenton et al. 2008[8]). Later IAM modeling runs that include risk aversion to these events find higher estimates, or that the optimal policy mix includes much greater and earlier mitigation action (e.g. Cai et al. 2015[9,10]).

A more recent issue over the use of exogenous growth rates in these models.[11] A number of recent econometric studies challenge this assumption, indicating that climate change will reduce growth rates. As a consequence, these tend to report much larger economic costs from climate change, e.g. with global average incomes estimated as 20% lower in the long term, and much lower (75%) in the poorest countries (Burke et al. 2015[12]).

Studies undertaken since the IPCC Fifth Assessment Report (or AR5, 2014) generally (though not always) report much higher estimates of the economic costs of climate change. This reflects more negative findings in the climate science (e.g. higher levels of sea-level rise as projected in the IPCC SROCC[13]), as well as the greater coverage of climate impacts including extreme events. These higher values are seen in updates to existing models. For example, updates to the DICE model have led to increasing values (Nordhaus 2017[14]), as well as studies that update the functions in Integrated assessment models (e.g. Howard and Sterner 2017[15]).

There has also been a new set of additional modeling approaches and models, with values from computable general equilibrium (CGE) models (e.g. Kompas et al. 2018[16], COACCH 2021) as well as econometric studies that consider the effects of climate change impacts on growth rates as well as output (Dell et al. 2012; Burke et al. 2015[17]; Burke et al. 2018[18], Kahn et al. 2019[19]). While there is debate about some of the econometric studies in the literature (Newell et al. 2021[20]), these studies tend to lean towards higher long-term impacts because of compounding effects.

In general, CGE models estimate higher relative impacts of climate change on GDP for Africa. For example, the OECD (2015)[21] CIRCLE study using the ENV LINKAGES (GGE) estimated economic costs to 2060 (note this is for market impacts only as captured in the CGE framework) and estimated global impacts of 2% by 2060, but impacts of 3.8% by 2060 for Sub-Saharan Africa specifically. The studies by Kompas et al. (2018) report values for a selection of African countries at between 0.3% and 6.7% per year by 2050 for a 3°C scenario, rising to 0.6% to 11% of GDP by 2070, but also report much higher damages for 4°C outcomes, especially for African LDCs (up to 27% of GDP). Many econometric studies present high estimates. AfDB (2019)[22] and Baasch et al. (2020)[23] estimate losses at 0.6% to 3.6% of per capita GDP, even by 2030, rising to 5% to 10% by 2050 for low- and high-warming scenarios, and report that some of the most affected countries in Africa could lose up to 15% of GDP by 2050.

However, Kahn et al. (2019) report lower values for Africa than many other world regions, with estimates of 0.1% to 4.2 % loss of GDP per capita for individual African countries in an RCP8.5 scenario in 2050, rising to 0.2% to 12.6 % by 2100, but lower and even positive values for RCP2.6.

THE EFFECT OF CLIMATE CHANGE ON SOVEREIGN CREDIT RATINGS

To inform this study, a literature review was made of the recent studies on the effects of climate change on sovereign credit ratings and wider risks to the public finances.

Moody's (2016[24]) report that sovereign ratings of individual countries are quite strongly correlated with their susceptibility to climate change, due to the overlap between the factors for assessing sovereign credit profiles and those driving exposure and resilience to climate change. It also reports that countries with an overarching reliance on agriculture, and where the quality of infrastructure is typically weaker (important aspects of susceptibility to physical climate change), tend to be rated lower. Finally, institutional strength is generally higher amongst sovereigns with a lower susceptibility to physical climate change. Their analysis identifies Sub-Saharan Africa as one of the most vulnerable regions.[25]

Similar findings accrue from an earlier review: Standard and Poor's Sovereign Risk and Climate Change analysis (2014). ICBS and SOAS (2018)[26] report that climate risks are already reflected in ratings for the vulnerable countries, and have led to an increase of ~10% on interest costs on government debt, raising the cost of private external debt, i.e. increasing the cost of capital (see also Kling et al. 2018 and Kling et al. 2020[27]).

Volz et al. (2020[28]) looked at the transmission channels from climate change to sovereign risk, and further at the macroeconomic impacts of climate change, the impacts of climate risk on financial sector stability, the effects on international trade and impacts on international capital flows, and the impact of climate change on political stability (although with a focus on Southeast Asia). They estimated the impact of climate vulnerability on sovereign risk, and found sovereign bond yield premia of around 155 basis points for the Association of Southeast Asian Nations (ASEAN) and 275 basis points for economies that are highly exposed to climate risk. They conclude that climate change will increase the cost of capital of climate-vulnerable countries and thereby threaten debt sustainability.

CFA Institute (2020)[29] assessed the risk of climate change on capital pricing for developing countries. This looked at whether (and how) climate risks were impacting investor behavior and cost of capital for developing countries. This included interviews with investors. For physical risks, they found investors do recognize some types of investment carry financial exposure from climate impacts, in terms of damages associated with costs of extreme weather events (physical risk). Other financial impacts from climate risks were either too intangible, or were manageable in the context of their overall portfolio exposure. However, awareness is rising, especially with the increasing take-up of the Task Force on Climate-Related Financial Disclosures (TCFD) framework.

In a recent study, the IMF (2020[30]) has investigated the impact of climate change vulnerability and resilience on sovereign bond yields and spreads in 98 advanced and developing countries over the period 1995–2017. It finds that the vulnerability and resilience to climate change have a significant impact on the cost of government borrowing, after controlling for conventional determinants of sovereign risk. Countries that are more resilient to climate change have lower bond yields and spreads relative to countries with greater vulnerability to risks associated with climate change. Furthermore, partitioning the sample into country groups reveals that the magnitude and statistical significance of these effects are much greater in developing countries with weaker capacity to adapt to and mitigate the consequences of climate change.

Klusakab et al. (2021[31]) simulated the effect of climate change on sovereign credit ratings for 108 countries, i.e. attempted to produce a climate-adjusted sovereign credit rating. They find evidence of climate-induced sovereign downgrades as early as 2030, increasing in intensity and spreading to more and more countries over the century. These impacts are almost eliminated if the Paris Goals are met (i.e. RCP2.6). Conversely, under a high–emission pathway (RCP8.5), 63 sovereigns experience climate-induced downgrades by 2030, with an average reduction of 1.02 notches, rising to 80 sovereigns facing an average downgrade of 2.48 notches by 2100. They calculate the effect of climate-induced sovereign downgrades on the cost of corporate and sovereign debt. Across the sample, climate change could increase the annual interest payments on sovereign debt by US$ 22–33 billion under RCP 2.6, rising to $137–205 billion under RCP 8.5. The additional cost to corporates is $7.2–12.6 billion under RCP 2.6, and $35.8–62.6 billion under RCP 8.5. The study uses economic cost inputs (on the costs of climate change) from Kahn et al. (2019).

THE ECONOMIC CASE FOR ADAPTATION IN AFRICA

To provide the benefit to cost ratio assessment for adaptation options, an evidence review was made. As this review was based on the available evidence, the findings are partial, and can only be considered as indicative. Furthermore, it is stressed that there are a very large number of caveats in transferring the results of existing cost-benefit studies of adaptation. This is due to the high site- and context-specificity, but also because the long time periods and high levels of uncertainty make quantification of benefits—and thus economic analysis—challenging. The focus here been on adaptation interventions that deliver high economic benefits today, i.e. no- and low-regret options. The review has found an increased body of evidence to back up the emerging message that adaptation has high benefit to cost ratios. That evidence is presented before under a number of relevant heads.

1. **Weather and climate information services, including early warning systems.** This includes a range of services including hourly, daily and short-term weather forecasts (e.g. for up to 10 days) through to climate services (e.g. seasonal forecasts). There are a number of international reviews of the benefit-to-cost ratios of these services that show high BCRs (Clements et al. 2013[32], WMO 2015[33], ECONADAPT 2017[34]) which generally report average values around 10:1 and a range from 2:1 up to 36:1. Economic benefits arise from the use of services to improve decisions (the value of information). These provide immediate benefits, and these usually increase with increased levels of climate change, though there is an increasing focus on extending W&CIS to adaptation services. Values vary with site and location, and benefits depend critically on the delivery of climate information along the value chain (forecast accuracy, communication and reach, uptake and use, effectiveness). While historically the focus has been on agriculture, W&CIS can provide important benefits for multiple sectors, e.g. energy, water, tourism, health and others. This review has focused on studies concentrating on Africa.

    - There are several studies that have looked at the BCRs of investing in improved foundational activities to improve forecasting. Hallegatte (2012[35]) estimates the BCR for improving met/hydro services in developing countries at 4:1 to 36:1, largely driven by EWS benefits. Kull et al. (2016[36]) looked at the economic benefits of strengthening global to national hydrometeorological services through cascading forecasting, and estimated BCRs of 81:1. Kull et al. (2021[37]) assessed the benefits of surface-based meteorological observation data, and the role in improving Numerical Weather Prediction (and thus improved forecasting). The study reported a BCR of over 25, with particularly strong benefits for Africa estimated at $0.35 billion/year for the continent.
    - In terms of improved weather and climate services, Clements et al. (2013)[38] identified 13 W&CIS studies in Africa that assessed benefits, although these often do not include BCRs. These include multiple sectors, including studies on agriculture in Kenya (Hansen et al. 2009) and South Africa (Jury, 2002), and hydropower in Ethiopia (Block 2011), as well as economy-wide benefits in Mozambique (Arndt and Bacou 2000).
    - Vaughan et al. (2019[39]) undertook a detailed review of 59 W&CIS studies in Africa, including ex-ante and ex-post information. They found a wide range of benefit levels; benefits were generally lower in African studies than in those dealing with the OECD, because of the level of capacity of end users and the effectiveness of the use of information. Nonetheless, many studies were found to report high economic benefits (though very few reported BCRs). These included a number of studies for agriculture, with Sultan et al. (2010) and Lo and Dieng (2015) in Senegal, Roudier et al. (2012) in Niger, Roudier et al. (2014) in Senegal, Anuga and Gordon (2016) in Ghana, Zongo et al. (2016) in Burkina Faso, Rodrigues et al. (2016) in East and South East Africa, and Tarchiani et al. (2018) in Mauritania.
    - Watkiss et al. (2021) undertook a series of economic CBAs in East Africa for the WISER project, looking at early warning systems for informal settlements in East Africa (BCR of 20:1), weather and climate information in Tanzania (16:1), seasonal forecasting in Uganda (26:1) and seasonal forecasting in Western Kenya (7:1).
    - Early warning systems can include short-term (hourly to weekly) forecasts of major extreme events, such as floods, as well as longer-term seasonal early warning, e.g. for droughts. These are generally reported as having high BCRs, e.g. with the GCA (2019) reporting a value of 9:1. Law (2012[40]), cited in WMO (2015), estimated BCRs of 3:1 to 6:1 for the benefits of Ethiopia's Livelihoods, Early Assessment and Protection (LEAP) drought early warning and response system. Watkiss et al. (2021) undertook a CBA for marine early warning information on Lake Victoria, and found a BCR of 16:1, driven by the combination of avoided deaths and fuel savings. Benefits of EWS are projected to increase under future climate change, because of increasing extreme weather events, although costs and residual damage will increase as well. These EWS have focused on flood and windstorm-related hazards. In the OECD, there is a greater focus on heat alert warnings, which have been found to have high BCRs (greater than 10:1) (Ebi et al. 2004[41], Hunt et al. 2016[42], Chiabai et al. 2018[43]). There may be some potential for similar systems in major Africa cities.

2. **Social protection and adaptive social protection programs.** Many African countries have social protection programs, which often include public works and cash transfers. These are often targeted at climate variability (lean seasons) or shocks.

    - For cash transfer programs, DFID (2011[44]) identified 8 studies (4 ex-ante, 4 ex-post), with BCRs that range from 1.0 to 6.2, including studies on Ethiopia (1.8–3.7:1), Ghana (1.3:1), Uganda (1.5:1). A four country study reported in Cabot Venton et al. (2013[45]) reviewed BCRs of: 3.4:1 for Burkina Faso; 2.2:1 for Chad; 3.7:1 for Mauritania; and 1.1 for Niger from a combination of cash transfers and green public works (rehabilitating land, development of water retention pools).
    - Investment in social protection has particular benefits in reducing the effects of climate shocks on poverty. The World Bank identifies social protection (Hallegatte et al., 2016[46]) as a form of climate-sensitive development for small and frequent shocks, and reports high benefit to cost ratios for African countries, although it notes that for larger shocks, additional interventions are needed.
    - More recently, there has been a focus on adaptive social protection programmes, i.e. to make these programmes climate-smart. These include investment in green (resilient) public works as well as contingency funding for shock response, i.e., forecast-based financing involving payments in advance of a major projected shock, notably droughts. Ex-ante BCRs have been undertaken for programmes in Ethiopia (4.4:1)[47] find high BCRs for adaptive social protection programming.

3. **Climate-smart agriculture.** Climate-smart agriculture aims to deliver triple outcomes: productivity (income growth), mitigation, and adaptation. Actual delivery on the three areas varies by practice and context. This supporting paper considers delivery against adaptation. The main CSA options are centred around sustainable agricultural land management (SALM) practices that improve soil water infiltration and holding capacity, as well as nutrient supply and soil biodiversity. They also include agroforestry, soil and water conservation, reduced or zero tillage, and the use of cover crops.[48] These reduce current climate-related risks from rainfall variability and soil erosion and also have potentially large co-benefits (mitigation, wider environmental benefits).

    - Studies of CSA find positive benefit to cost ratios. For example, economic analysis (primarily ex–ante) of 32 country-level projects in IFAD's Adaptation for Smallholder Agriculture Programme estimated a median BCR of approximately 2:1, but with a range from 1:1 to 6:1 (Ferrarase et al. 2016[49]). This included studies in Benin, Chad, Djibouti, Egypt, The Gambia, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Morocco, Mozambique, Niger, Nigeria, Rwanda, Sudan, Tanzania and Uganda. Social Returns on Investment (SROIs) of 1.3–4.7: 1 for representative investments channelled through the private sector are also reported (IFAD 2018[50]). There are studies that look in detail at specific options, finding positive economic returns for some (but not all) interventions, e.g. Branca et al. (2012[51]) in Malawi, ECA in Mali[52], and Mujeyi and Mudhara (2020[53]) in Zimbabwe. They reveal that there is high site specificity on climate-smart agriculture, i.e., the same measures can have widely differing BCRs even across a country, as found in Ethiopia.[54]
    - However, there is a recognition that CSA measures often include important opportunity, transaction and implementation costs,[55] e.g., when labour costs are considered, or when the program costs of reaching large numbers of smallholder farmers are considered. Positive EIRRs are usually conditional on including all non-market benefits and low discount rates, the latter because schemes take time to mature and deliver benefits.[56] Modelled returns are often contingent on widespread adoption by farmers, which do not always materialise.
    - For individual practices, measures are often highly site-specific, reflected in large BCR differences for similar interventions in different places. There is varied evidence on practices as viable standalone adaptation strategies. Evidence is highly country-, risk-, site- and context specific.

4. **Climate-resilient varieties.** The literature reports that drought- and flood-tolerant crops are an effective and efficient adaptation strategy in many countries. BCRs are positive, though they tend to be modest. Prasad et al. (2014[57]) made a review of 27 interventions in India and found benefits from the planting of drought-tolerant paddy varieties (BCRs 1.5:1 to 3.2:1), as well as submergence-tolerant or flood-resistant varieties (BCR 1.6:1 to 3.3:1), as compared to existing varieties. Shongwe et al. (2014[58]) found switching to drought-resistant crops in Swaziland had a high net present value (NPV). Wamatsembe et al. (2017[59]) found drought-tolerant hybrid maize in Uganda had lower returns and a value/cost ratio of 1.5. Studies in South Africa also found BCRs of 1.9:1 for drought-resilient varieties.[60] However, availability of suitable varieties is a constraint to adoption, and there are barriers (financial, cultural) to uptake. The performance of new varieties is also highly site-, location- and context-specific, as it relates to the level of current risk, and the shifts in optimal/tolerable suitability zones and patterns of extremes under climate change. There are studies that show that R&D into new improved crop varieties (which are high-yielding and tolerant to pests/diseases and drought/flood/salinity) is an effective adaptation strategy, with an average BCR of 27 (based on a large study).[61] Other studies report high BCRs for similar research at 2:1 to 17:1.[62]

5. **Irrigation.** Modeling studies indicate high benefit to cost ratios for irrigation as an adaptation option, with academic literature projecting wide uptake (globally) under future climate change.[63] However, some literature is not as positive, e.g., finding the BCR of groundwater irrigation was low (1.6:1) although found this rose to 2:1 under climate change.[64] Studies also find impacts on irrigation performance/return from future climate change,[65] hence the need to ensure that the design of such interventions is climate-smart. BCRs depend on the type of irrigation (gravity, surface, drip, etc). Some climate studies report higher BCRs for drip systems over sprinklers,[66] though in these cases, alternative climate-smart agriculture options have even higher BCRs. Further, some studies highlight the risks of irrigation lock-in and maladaptation under a changing climate, especially in drought-prone areas where there is likely to be multi-sectoral competition for water. There are also potential trade-offs with mitigation objectives if the source of energy for pumped irrigation is diesel, due to GHG emission dis-benefits.

6. **Health.** There is evidence that existing health protection measures are extremely effective in dealing with anticipated increases under climate change (Ebi 2008[67]) for food-borne (including diarrheal illness), water-borne and vector-borne (malarial) disease. Studies also highlight low-regret options of increases in monitoring and surveillance, which are especially important for climate change (and changes in prevalence and incidence of disease). These options also have high distributional benefits (i.e., they are pro-poor).

7. **Water.** Water, sanitation and hygiene (WASH). A review of 7 CBA studies (Hunt 2011)[68] reports a wide range of outcomes depending on option and context (OECD vs LDC). The BCRs were positive, with values of 2–3:1 in most studies, with one study (Hutton et al. 2007[69]) reporting BCRs of 5 to 46:1 in developing regions and 5 to 12:1 for the LDC context. A review of the economics of adaptation for WASH and WRM (water resource management) summarizes several studies but does not report BCRs (ODI 2014[70]).

   Mohamed (2013)[71] found, for example, that conversion from flood to drip irrigation (in the Tadla region in Morocco) could improve farm-level net returns and public net benefits. In addition, the NPV of drip irrigation for small-scale farmers could be improved if the technology was extended to include food crops rather than limiting it to cash crops. Lunduka (2013[72]), studying the Lake Chilwa catchment in Malawi, found win-win outcomes for the local farming and fishing community if soil and water conservation techniques complemented irrigation and rain-fed agriculture.

8. **Disaster risk reduction and management.** There is a robust international literature on the economic benefits of disaster risk reduction and management. General reviews, such as studies by the World Bank (2012)[73] and a systematic review by Mechler (2016[74]), find high BCRs. The latter (based ex-ante and ex-post) found average BCRs of 5:1 for flood-related risks, and 4:1 for windstorms, but none of these were for Africa. Shreve and Kelman (2014[75]) undertook a review of the cost-benefit ratios for disaster risk reduction, which highlighted the potentially high benefits, but also the challenges and limitations of such analysis. It found an extremely wide range of BCRs for DRR, with maximum values from 3:1

to 60:1 (with one outlier above this). However, this only includes one study in Africa, namely the study of Venton et al. (2010) for drought in Malawi (maximum BCR 24:1), and one outlier with a very high BCR in Sudan.

Cabot Venton et al. (2013)[76] reviewed benefit to cost ratios for 23 field-tested community-based adaptation DRR pilots worldwide in terms of humanitarian aid avoided from social protection and early intervention, finding BCRs of 1.8–2.7:1. Incorporating the value of avoided losses increases these BCR estimates to 2.3–3.3:1. This includes interventions in Africa for Kenya and Sudan (not quantified); for Malawi for drought with crop diversification, soil and water conservation, and drought-resilient livestock (BCRs of 24:1); for The Gambia for drought ex-post, finding BCRs of seeds and fertilizers (3.3); fire belts (38.7); and tree-planting (2.6); and Kenya for drought of 1.5–3:1.

9. **Flood protection.** There is also a large international literature on the BCRs of investments for flood protection, including to climate change. As well as the studies above (Shreve and Kelman 2014; Mechler 2016) the ECONADAPT study (2015)[77] compiled a database of DRM investments for floods in Europe containing 110 observations on investments/projects from 32 studies and databases, covering 16 European countries, and including ex-ante and ex-post studies. The study found that investments in flood risk protection in Europe had, on average, a BCR of 6:1, whilst the median BCR was 3:1. DRM investments that enhanced preparedness to disasters had the highest economic returns, while investment that mitigated the damage of floods following the event also showed high BCRs. Preparedness had the highest mean BCR (11:1), followed by ex-post flood damage mitigation (BCR = 8.5:1), and "hard" flood control such as dikes (4.1). In all cases, BCR results are very site- and context-specific and vary further depending on whether intangible as well as tangible benefits are included, and whether indirect effects are included. They also depend on the objectives used for setting flood protection levels, i.e., whether based on the economic optimal level or to meet acceptable risk levels (i.e., defined return levels for standards of protection). When considering future climate change, a number of studies show that BCRs are similar or larger than those for the present day for coastal and river flooding. There are sectoral models that find high BCRs for Africa for coastal and river flood protection.

AdaptCost (2010)[78] assessed economic costs of sea level rise for all coastal countries in Africa, the costs of adaptation, and the benefits of adaptation, using the DIVA model, but it did not estimate BCRs. The analysis shows that adaptation can reduce the risk of flooding and the economic costs of sea level rise very significantly, at relatively low cost. The same model was used in the global Economics of Adaptation to Climate Change (EACC) Study[79] to present values for the Africa region. This model has also been applied in numerous country studies in Africa, such as Kenya, Tanzania, Ghana and Mozambique. However, it should be noted that these studies often apply highly stylised modeling rather than real policy investments and/or decision making under uncertainty.

10. **Making new infrastructure climate-resilient.** Infrastructure often has a long life cycle, and new infrastructure built over the next few years may operate under a very different climate to today. If these future risks are not considered, climate change will cause asset damage or failure, and affect operating costs and/or revenues. There is an opportunity to design infrastructure to be climate-resilient when it is built. Recent analysis by the World Bank has identified that on average, building climate resilience into new infrastructure involves low marginal cost, and has a benefit to cost ratio of 4:1 (Hallegatte et al. 2019[80]). This analysis was further refined in the Global Commission on Adaptation (2019) report,[81] which also reports BCRs of 4:1 (with a range of 2:1 to 10:1). However, both these studies are highly aggregated and stylised, and they are not based on specific ex-ante or ex-post review of projects. Actual analysis of the costs and benefits of making specific infrastructure climate-resilient shows these are extremely site- and context-specific (e.g., ADB 2014[82]; ADB 2021[83]), and BCRs vary with the objectives set for adaptation as well as the adaptation options considered. They also vary with climate change and scenario projections, how uncertainty is included (with decision-making under uncertainty), as well as discount rates. There is therefore a very large range of potential BCRs, including the potential for economic maladaptation (BCRs <1). Including resilience is particularly important for new critical infrastructure,[84] because of the risks of cascading risks (or to put another way, the benefit to cost ratios of critical infrastructure resilience are much higher, because of the additional benefit of reducing cascading impacts). However, in practice, climate-proofing infrastructure is complicated because of uncertainty.

- Climate resilience with decision-making under uncertainty for climate-sensitive infrastructure (hydropower, irrigation) or infrastructure siting, as well as adaptation, can include the concepts of robustness, flexibility, real options in the use of portfolios (that combine technical and non-technical options), and minimising regrets.[85]

- Examples are risk-specific, but include initiatives for coastal protection. For example, Linquiti and Vonortas (2012) analysed coastal protection investments and found using real options led to better use of resources in Dar-es-Salaam, Tanzania[86]; hydropower plants in Ethiopia[87]; and RDM application for agriculture in Nigeria (Mereu et al, 2018)[88]

- This also includes iterative adaptive management, which includes a cycle of monitoring, research (including pilots), demonstration, evaluation, and learning to improve future management strategies or decisions (FRDE 2014).

For existing infrastructure, several studies highlight enhanced maintenance regimes[89,90], notably for drainage and sewage systems, but also for roads. Similar benefits are likely for most infrastructure in relation to climate extremes.

11. **Ecosystem-based adaptation (nature-based solutions).** EBA involves alternatives to hard engineered protection, such as mangroves and wetlands (storm surge), room-for-river through to small scale (sustainable urban drainage). These are currently highly recommended, but evidence for their impacts is limited. Note, however, that these options have large co-benefits in addition to direct climate benefits.

    - Coastal EBA was reported to have among the highest BCR for coastal resilience (e.g., mangroves[91,92]) when co-benefits were included, but more detailed analysis finds modest BCR due to fact that they take time to establish, they have high opportunity and transaction costs, and there are limits to effectiveness. High BCRs are conditional on including non-market benefits and low discount rates. Some EBA schemes (e.g., sand dunes, offshore sand banks) offer greater flexibility and lower capital costs than hard alternatives, but maintenance costs are higher, and so BCRs are affected by the discount rate. Note that EBA interventions often not sufficient to reduce all damages (such as residual damages) on their own. Thus there are limits to their applicability (especially for larger risks). However, there is an increasing use of EBA as part of a portfolio, i.e., combining these measures with hard schemes. Some cities are moving to portfolio solutions (e.g., large-scale flood protection, wetland restoration, buffer zones and increased building codes,)though high land cost is often an issue for urban EBA because of the high area footprint of such measures.

Mangroves are reported to have high BCR for coastal resilience,[93,94] which is driven by the high value of ecosystem services that they provide,[95] including GHG mitigation, provisioning and regulating, and recreational services, both direct and indirect.

12. **Forestry.** One particularly important EBA option is forestry. Forestry can deliver adaptation benefits through enhanced watershed management and soil erosion protection. It also offers large co-benefits from its role in livelihood and economic benefits (for instance, the sale of timber and non-timber products), as well as broader ecosystem service benefits.[96]

13. **Insurance.** Insurance is often reported as a low-regret option,[97] but the evidence varies. International studies[98] report high BCRs (10:1) in Malaysia for flood insurance but modest BCRs for insurance in India (2:1) and note that there is often a need for subsidies to make insurance affordable. Insurance often performs modestly when compared to other options. For example, in India insurance had one of the lowest BCRs.[99] Insurance BCRs are strongly influenced by the frequency of events and premiums. However, insurance is a complementary tool to adaptation as it spreads out the financial risks of probabilistic extreme events. It should not be seen as an answer to address slow-onset change (trends) or frequent events because premiums become unaffordable.

- As climate change increases weather extremes, increasing risks will be factored into premiums, which will lead to differential pricing and make it harder to obtain insurance (at low cost) for more vulnerable individuals and places.
- There is also a literature on national risk pooling facilities.[100] The Africa Risk Capacity[101] is an example of macro and regional risk pooling. For a CBA, see Republic of Senegal (2013[102]).
- Development cooperation providers have also pioneered the use of prearranged credit lines to provide rapid access to funding following an extreme weather event (Campillo et al. 2017[103]).

While there are many proponents of micro-insurance, notably index-based schemes, there is varying evidence on the actual BCRs. There are some moderately positive BCRs for index-based insurance (e.g., drought in India, BCR 2:1[104]) though interestingly it was found that the BCR dropped under climate change (to 1.2:1) because of changing risk patterns. Micro-insurance products are quite expensive (as they involve higher product design and marketing costs) and there are issues of affordability, which means take-up is too low at market prices and subsidies are required. Some also argue that micro-insurance can create perverse incentives, such as reducing risk diversification. This is leading to more interest in index-based insurance for meso- and macro-level insurance. The empirical evidence shows low uptake by farmers due to a range of barriers: mainly financial (high cost), behavioural (personal perceived risk; low trust in providers), and technical (basis risk).

14. **Capacity building and institutional strengthening** is generally reported as being extremely effective, but is very challenging when it comes to valuation. There have been some international reviews (LSE 2016)[105] that identify high economic benefits as well as a number of context-specific studies that have estimated BCRs, reporting results of >10:1, though these are not specific to the African context.[106] In one study from South Africa, Cartwright et al. (2013) compared institutional options against hard options in Durban in the context of adaptation and found these had among the highest BCRs.[107] A number of studies report higher BCRs when capacity building/institutional strengthening are combined with outcome-orientated adaptation options. A portfolio of improved seeds, soil and water conservation, and better extension services and improved climate information was most effective in enhancing agricultural production in climate vulnerable areas.[108] Institutional strengthening and capacity building (including technical assistance to support implementation of climate adaptation options and investments in climate–sensitive sectors such as water) increases the efficiency of implementation.[109]

The next section of this paper will elaborate the methodology used for the comparative analysis of the costs of action and of inaction for a suite of adaptation solutions in Africa.

AGRICULTURAL AND FOOD SYSTEMS

Climate change is already stalling progress towards food security in Africa. African agriculture and food systems are already palpably suffering the impacts of climate change. Visible effects include changes to the start and end dates of growing seasons, and the frequency and intensity of dry spells and heavy rainfall events.

Appropriate investments in the agriculture sector can help food systems adapt by increasing productivity, resilience, and resource-use efficiency. This paper estimates the cost of building resilient agricultural and food systems versus the cost of inaction.

ESTIMATING THE COST OF ACTION

We identified five priorities for public sector investment in adaptation in Africa based on the literature, primarily informed by IPCC AR5 and Special Report on Climate Change and Land and the CGIAR and IMF analyses of food system adaptation costs (IMF 2020).[110,111,112,113] These areas are: **agricultural R&D, water management, infrastructure, sustainable land management and climate information services.** These are presented in Table 1 along with a range of other complementary adaptation solutions.

Table 1: Climate change adaptation solutions for African food, land, and water systems

Key: high medium low

Family of adaptation solutions		Adaptation benefits	Food security co-benefits	Mitigation co-benefits	Priority for public sector investment	Early examples in Africa (expanded in text below)
Public policy and incentive solutions	**Ramp up support to research and extension services**	high	high	high	high	Mauritius, Namibia, Botswana
	Strengthen inclusive climate information & risk management services	high	high	low	high	Senegal, Rwanda, Angola
	Implement insurance schemes against shocks, and wider social safety nets to counter climate risks	medium	high	low	medium	Ethiopia, Mauritania, Niger
	Repurpose subsidies and eliminate policy distortions that increase climate vulnerabilities	high	high	low	low	Botswana, Senegal
	Deploy mitigation policy and finance in ways that support adaptation	medium	medium	high	low	Climate-Smart Agriculture Investment Plans, e.g. Mozambique, Mali
	Reduce barriers to trade in times of crisis	high	high	low	low	African Continental Free Trade Area
Food value chain and livelihood solutions	**Provide and maintain adaptive climate-resilient infrastructure**	high	high	low	high	Malawi, Zambia
	Reduce and manage food loss and waste	medium	high	high	medium	The Gambia, Malawi
	Create demand for affordable healthy low-carbon diets	high	high	high	low	South Africa, Egypt
	Link small-scale producers to value chains	medium	high	low	low	Nigeria, Rwanda
On-farm and productive landscapes solutions	**Improve sustainable water management at farm and catchment levels**	high	high	low	high	Burkina Faso, Madagascar
	Restore degraded landscapes and practice sustainable land management	high	medium	high	high	Ethiopia, Niger
	Scale up context-specific climate-smart soil management	high	high	high	medium	Zambia, Ethiopia
	Improve livestock management	medium	high	high	medium	Kenya, Nigeria
	Monitor and manage new trends in pests and diseases	medium	high	low	medium	International networks and services, e.g. FAO and CABI
	Promote diversification of crops and livestock	high	medium	medium	low	Morocco, Rwanda
	Use climate-ready species, cultivars, and breeds	medium	high	low	low	Pan-African—but adoption levels need to be raised
	Incorporate perennial crops, including agroforestry	medium	medium	high	low	Zambia, Côte d'Ivoire

Key sources for adaptation solutions: Niang et al., 2014; Mbow et al., 2019; Shukla et al., 2019; IMF 2020; Sulser et al., 2021 (country examples sourced more widely)[114]

The figures on adaptation costs for agricultural R&D, water management, and infrastructure draw primarily from the CGIAR assessment, which utilized IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), a modelling framework that links climate, crop, water, and economic models to analyse scenarios of future change in agricultural production, consumption, prices, and trade at national, regional, and global scales. IMPACT produces reference scenarios to 2050 assuming no climate change as well as different levels of climate change and socioeconomic assumptions from the IPCC, capturing a wide range of possible climate and socioeconomic futures shown in Table 5. Together with the reference scenarios, Sulser et al. (2021[115]) analysed scenarios of how plausible investment options—including investments in agricultural R&D, water management, and infrastructure—could help offset the potential impacts of climate change. The assessment used the number of people facing chronic hunger as the core indicator of climate change impacts and adaptation. Chronic hunger was calculated based on per capita calorie availability (including access via international trade) and minimum dietary energy requirements, following a methodology equivalent to the FAO prevalence of undernourishment indicator (Robinson et al. 2015[116]). The target for adaptation is to offset the effects of climate change by making investments that reduce the number of hungry people projected in 2050 to the same level that would be achieved in the absence of climate change.

Table 2: Description of scenarios in the IMPACT model

Reference	With no climate change (NoCC; constant 2005 climate with various Shared Socioeconomic Pathways (SSPs))
	With climate change (CC; combinations of SSPs and Representative Concentration Pathways (RCPs) across a range of General Circulation Models (GCMs))
Agricultural R&D	Increased research and development (R&D) investment across the CGIAR portfolio plus faster and more eficient adoption of new technologies
Water Management	Expansion of irrigated area coupled with increased water use efficiency
	Improved soil water-holding capacity
Infrastructure	Infrastructure improvements to improve market efficiency through the reduction of transportation costs and marketing margins (rail, road, port, and electrification)

Source: Sulser et al. (2021).

Notes: The no climate change scenario is defined by Shared Socioeconomic Pathway 2 (SSP2), while the reference with climate change scenario is defined by the combination of SSP2 with RCP8.5 via the UK Met Office Hadley Centre Earth System Model (HGEM) General Circulation Model. Detailed descriptions of RCPs, GCMs, and SSPs are available from Moss et al. (2010), O'Neill et al. (2017), and Navarro-Racines et al. (2020)[117]

The soil water holding capacity scenario simulates the benefits of technologies—such as no-till agriculture and water harvesting—that increase soil water holding capacity or otherwise make precipitation more readily available to plants (that is, effective precipitation). Improvements vary by region and represent the different levels at which these kinds of technologies are currently being applied in various regions, with a maximum increase in effective precipitation of 5% to 15% by 2045. For water use efficiency (WUE), IMPACT uses the concept of basin efficiency, defined as the ratio of beneficial water depletion (crop evapotranspiration and salt leaching) to total irrigation water depletion at the basin scale. Basin efficiency in future years was assumed to increase at a prescribed rate in a food production unit (FPU) depending on water infrastructure investment and water management improvement in the FPU. For the WUE scenario, basin efficiencies are assumed to increase by 15% points by 2030 and then continue previous trajectories.

The infrastructure and market access scenario assumes a mix of transportation infrastructure improvements and increased rural electrification. These improvements enhance productivity along the food value chain, increase the speed of moving commodities to markets, and improve storage capacity. These improvements are represented as a reduction in the cost of moving goods from the farm to market and was modelled in IMPACT by adjusting the price wedges between producer and consumer prices, reducing the margin from producer prices to consumer prices by 1 percentage point per year between 2015 and 2030.

In addition to research and extension, water management and infrastructure, we include adaptation costs for two additional measures: sustainable land management and climate information services.

The estimated cost of **sustainable land management** builds on an AFR100 initiative that seeks to restore 100 million of degraded land in Africa by 2030. For this report we raised the ambition to 175 million hectares—that is, 25% of the often-cited Africa's 700 million hectares of degraded land by 2050.[118] At land restoration costs ranging from $500 per hectare for woodlands to $5,000 per hectare for wetlands, land restoration costs by 2050 were estimated at $187.21 billion, or $6.24 billion per year for Sub-Saharan Africa.

For **climate information services**, the critical investment areas include weather observation and ICT equipment, improved capacity to utilize global and regional climate forecasts and downscale them to high resolution for use at the local level, regulatory frameworks, applied research, early warning system dissemination and services, broad-based weather forecast communications to farmers, and project management. The estimated cost for 15 Economic Community of West African States (ECOWAS) countries and 7 Regional Centres is about $290 million and $35 million, respectively (Table 4).

Table 3: CIS National and Regional CIS Investment Needs for ECOWAS

	Regional ($)	National ($)
Early warning systems and services	8,000,000	127,000,000
Weather observation and ICT equipment	6,500,000	77,242,000
Institution strengthening and regulatory framework	11,500,000	55,935,000
Applied CIS research	5,500,000	10,500,000
Monitoring and coordination	3,000,000	18,949,000
Total	**34,500,000**	**289,626,000**

Source: World Bank (2021). Regional data is for 7 climate centres, while national data is for 15 countries.

At an estimated cost of $19.3 million per country and assuming an allocation of 60% of that cost for operations and maintenance, the investment cost for 46 Sub-Saharan African countries is $1.42 billion. Similarly, at an estimated cost of $4.9 million per regional centre and assuming 60% for operation and maintenance, the total costs for 20 regional climate centres for Sub-Saharan Africa is $157.7 million. The grand total for regional centres and national CIS combined is $1.58 billion, or $52.6 million per year over a 30-year period.

Table 4: Ecosystem Services Values from Sustainable Land Management in Sub-Saharan Africa by 2050

	Cropland		Evergreen forest		Deciduous Forest		Woodland		Grassland		Wetland		Total	
	$M	Proportion	$M	Proportion	$M	Proportion	$M	Proportion	$M	Proportion	$M	Proportion	$M	Proportion
Provisioning services	**100,705**	**71.6%**	**44,546**	**34.7%**	**101,915**	**34.7%**	**15,149**	**16.0%**	**73,938**	**45.5%**	**15,511**	**6.5%**	**351,765**	**33.2%**
Food	58,720	41.7%	4,874	3.8%	11,150	3.8%	3,101	3.3%	67,484	41.5%	5,737	2.4%	151,066	14.3%
Water	10,111	7.2%	658	0.5%	1,505	0.5%			3,397	2.1%	3,812	1.6%	19,483	1.8%
Raw materials	5,536	3.9%	2,047	1.6%	4,683	1.6%	10,139	10.7%	3,001	1.8%	3,971	1.7%	29,377	2.8%
Genetic resources	26,339	18.7%	317	0.2%	725	0.2%							27,381	2.6%
Medicinal resources			36,650	28.6%	83,852	28.6%			57		925	0.4%	121,484	11.5%
Ornamental resources							1,909	2.0%			1,065	0.4%	2,974	0.3%
Regulating services	**37,967**	**27.0%**	**61,628**	**48.1%**	**140,998**	**48.1%**	**3,042**	**3.2%**	**9,002**	**5.5%**	**162,242**	**67.6%**	**414,879**	**39.2%**
Air quality regulation			292	0.2%	669	0.2%							961	0.1%
Climate regulation	10,389	7.4%	49,809	38.8%	113,958	38.8%	418	0.4%	2,265	1.4%	4,560	1.9%	181,398	17.1%
Disturbance moderation			1,608	1.3%	3,680	1.3%					27,902	11.6%	33,190	3.1%
Regulation of water flows			8,334	6.5%	19,067	6.5%					52,383	21.8%	79,785	7.5%
Waste treatment	10,035	7.1%	146	0.1%	335	0.1%			4,246	2.6%	28,173	11.7%	42,935	4.1%
Erosion prevention	2,705	1.9%	366	0.3%	836	0.3%	775	0.8%	2,491	1.5%	24,360	10.2%	31,533	3.0%
Nutrient cycling	13,448	9.6%	73	0.1%	167	0.1%					16,007	6.7%	29,694	2.8%
Pollination	556	0.4%	731	0.6%	1,673	0.6%	1,849	2.0%					4,809	0.5%
Biological control	834	0.6%	268	0.2%	613	0.2%					8,858	3.7%	10,574	1.0%
Habitat services	**0**	**0.0%**	**950**	**0.7%**	**2,174**	**0.7%**	**76,105**	**80.4%**	**68,729**	**42.3%**	**22,940**	**9.6%**	**170,899**	**16.1%**
Nursery services			390	0.3%	892	0.3%	75,926	80.2%			12,026	5.0%	89,234	8.4%
Genetic diversity			560	0.4%	1,282	0.4%	179	0.2%	68,729	42.4%	10,914	4.5%	81,665	7.7%
Cultural services	**2,073**	**1.5%**	**21,128**	**16.5%**	**48,337**	**16.5%**	**418**	**0.4%**	**10,926**	**6.7%**	**39,273**	**16.4%**	**122,155**	**11.5%**
Aesthetic information									9,455	5.8%	12,073	5.0%	21,527	2.0%
Recreation	2,073	1.5%	21,128	16.5%	48,337	16.5%	418	0.4%	1,472	0.9%	20,660	8.6%	94,087	8.9%
Culture and art											6,541	2.7%	6,541	0.6%
Total	**140,745**	**100.0%**	**128,252**	**100.0%**	**293,425**	**100.0%**	**94,714**	**100.0%**	**162,595**	**100.0%**	**239,967**	**100.0%**	**1,059,698**	**100.0%**

Source: Own calculations based on the coefficients of de Goot (2012). The estimate is based on restoring 175 million ha of degraded land by 2050.

Table 5: Annual reference scenario and incremental investment costs for agricultural adaptation for Sub-Saharan Africa by 2050 ($ billion)

Scenarios	Research and extension		Water management		Infrastructure and market access	Sustainable land management	Climate information services	Total
	International agricultural research	National agricultural research	Efficient irrigation and increased water use efficiency	Improved soil water holding capacity				
Reference scenario ($billion)	1.11	1.11	3.11	0.39	0.18	-	-	5.90
Incremental costs ($billion)	1.66	-	1.42	1.20	1.90	3.35	0.053	9.58
Total	**2.77**	**1.11**	**4.53**	**1.59**	**2.08**	**3.35**	**0.053**	**15.48**

Sources: Sulser et al. (2021); World Bank (2021); and others' calculations

Notes: Sustainable land management includes vegetative measures such as agroforestry, tree planting, and natural tree regeneration, and structural measures such as terracing, flood control, cross slope barriers and other erosion control measures; Climate information services include hydrometeorological observation and ICT equipment, early warning systems and services, institutions, regulatory frameworks, and training. Infrastructure includes road, rail, and electricity; these help in linking rural communities to markets.

ESTIMATING COST OF INACTION

Research and Extension. The cost of inaction is based on the effects of R&D investments on agricultural total factor productivity (TFP) in Sub-Saharan Africa (Fuglie 2018[119]).[120,121] TFP indicates how efficiently agricultural land, labor, capital, and materials (agricultural inputs) are used to produce a country's crops and livestock (agricultural output), and it is calculated as the ratio of total agricultural output to total production inputs. Agricultural productivity growth to meet rising demand of the population for food reflects the impact of agricultural R&D, and governments have a role in creating the knowledge capital required for economic growth (Fuglie 2018).

In this paper we used R&D elasticity, the percentage change in productivity with a 1 percent change in the stock of knowledge to evaluate the impact of research on agricultural adaptation in SSA. The method followed to estimate elasticities was based on the average elasticity measure of Andersen (2015), adapting it to the calculation of disaggregated values of elasticities at different levels.[122] The steps include:

a) Calculated R&D elasticity of agriculture at the country level, using available measures of TFP growth and the aggregated knowledge stocks by country and year (KSht) using average values of TFP and knowledge stock growth for the period 1981–2018. An OLS regression of TFP growth against KS growth was fitted and the average elasticities were adjusted proportionally to reduce the dispersion of their values around the predicted value of the regression and correct for outliers.
b) An approximation of TFP growth by crop and livestock commodity was obtained using data on disaggregated output and input by country. Using average TFP and knowledge stock growth by commodity and country for the period 1981–2018, average elasticities by crop were obtained. The last step was to adjust all average commodity elasticities proportionally so that the sum of elasticities weighed by average output share for the period added up to the overall elasticity for agriculture calculated in step a).
c) Finally, the elasticities for the diverse types of knowledge stocks by crop (domestic investment, CGIAR, and public and private spillovers) were calculated using two pieces of information: i) the crop-specific R&D elasticities obtained as explained in b), and ii) average values of these different elasticities for different regions as summarized in Fuglie (2018[123]). The average values from Fuglie (2018[124]) were adjusted proportionally so that the final values added up to the elasticity value of each commodity calculated in b).

The next step focused on projecting agricultural productivity value added from 2021 to 2050. A socioeconomic outlook for African economies by the year 2060 exists that considers several drivers of change including international trade, technological change, population growth, urbanization, and climate change (AfDB, 2011). The AfDB report noted that median temperature increases of between 3°C and 4°C will occur over the entire Africa region. Temperatures are projected to rise by 3.6°C in the hottest part of the continent (the Sahara) and an average of 3.2°C in the coolest part (East Africa). The report also noted that real GDP for the whole of Africa is expected to grow steadily and peak at 6.6% per annum in 2020 before decelerating gradually to 5.4 percent per annum by 2060. The annualized growth rates for subregions within the continent shown in Table 7 were used to project annual agriculture GDP from 2021–2050.

Table 6: Annual GDP Growth Rates for Africa

	2020–2030	2030–2040	2040–2050
Central Africa	0.64%	0.47%	0.29%
East Africa	0.77%	0.83%	0.79%
Southern Africa	0.42%	0.51%	0.47%
West Africa	0.64%	0.47%	0.43%

Source: AfDB (2011) and own computations

African countries' agricultural research intensity, defined as agricultural R&D spending as a proportion of agricultural GDP, averages 0.74% compared to the minimum 1% recommended by the African Union. The Agricultural Science and Technology Indicators (ASTI) database indicate that about 85% of SSA countries—that is, 34 out of 40 countries—have research intensity values ranging from 0% for Chad and Guinea Bissau to 0.9% for The Gambia, Ghana, Lesotho, and Senegal (Figure 1). Only 6 countries—Botswana, Cabo Verde, Mauritius, Namibia, South Africa and Zimbabwe—spent more than 1% of agricultural GDP on agricultural R&D. The agricultural GDP estimates for 2021–2050 for SSA countries was multiplied by the R&D elasticities to obtain the increase in agricultural output that would be obtained if the countries were to increase their current R&D investment level to the African Union recommended level of 1% of agricultural GDP. The annual value of $71.21 billion represents the cost of inaction for research.

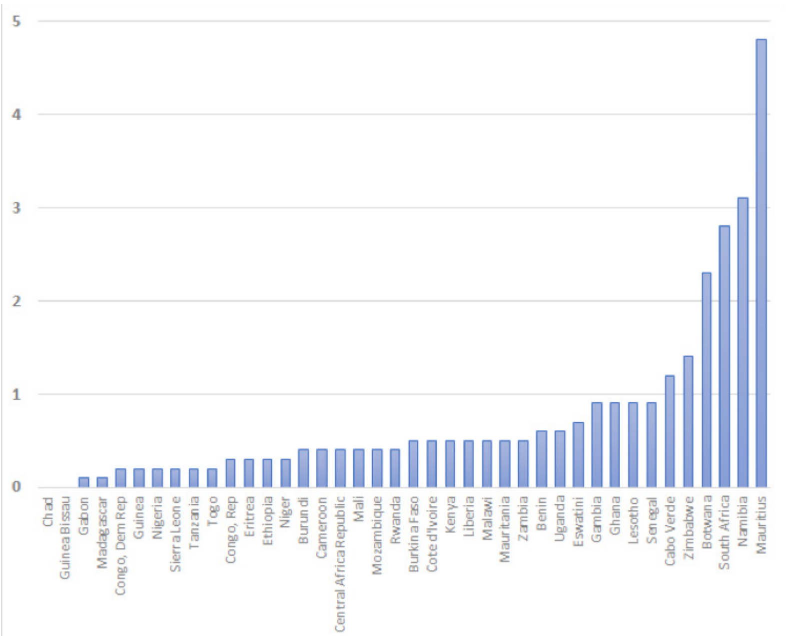


Figure 1: Agricultural Research Intensity in Sub Saharan Africa (%)

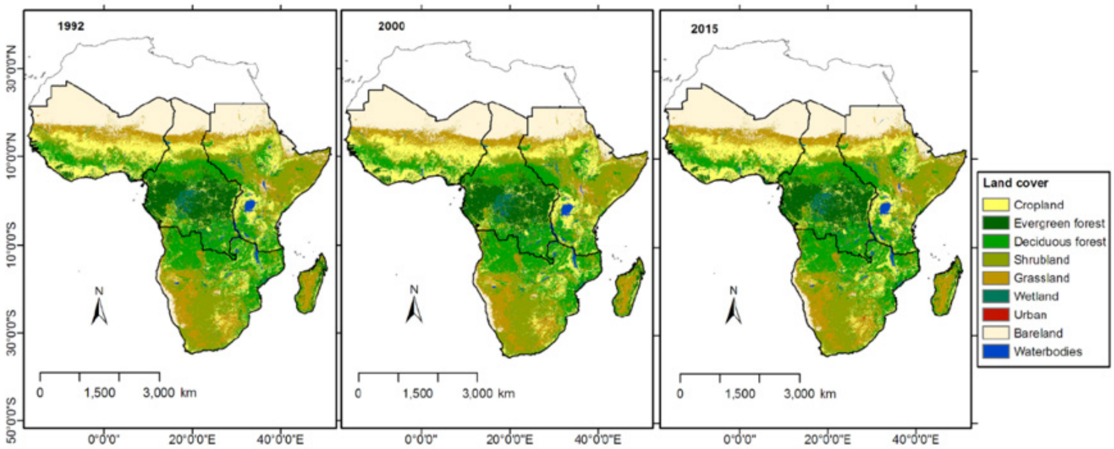
Source: ASTI database using the latest data for countries from 2011 to 2016

For **water management**, losses due to low, medium, and high severity droughts were assumed to have 0.33, 0.2 and 0.1 probabilities of exceedance respectively with corresponding agricultural losses of 20%, 50% and 100%.[125] Cost of inaction for water management was then estimated as the sum product of exceedance probability and monetary value of agricultural losses using the agricultural GDP values estimated above. Rural road rehabilitation significantly increases market access in Africa, with consumption growth increasing by 16% in Ethiopia.[126] This was multiplied by Sub-Saharan Africa's rural access index of 30% and agricultural GDP to estimate the cost of inaction for rural infrastructure.

The cost of inaction for **Climate Information Services** was derived by multiplying agricultural GDP by a vulnerability factor, the average annual direct economic losses caused by weather and related hazards as a share of GDP (3%), with loss factor, agricultural production losses avoided due to access to climate information services set at 20% (World Bank, 2012).

Sustainable land management. The cost of inaction for sustainable land management was estimated as the monetary value of the ecosystem services provided by 175 million ha to be restored by 2050. The Ecosystem Services Value (ESV) concept treats natural assets such as ecosystems as components of wealth, well-being, and sustainability. It helps to demonstrate the importance of ecosystems to policy makers and provides evidence for decision-makers for more effective natural resources management.[127] Multitemporal land cover maps and for Sub-Saharan Africa and areal extent of major biomes were used as inputs for the ESV quantification (Figure 2 and Table 7).

Figure 2: Land cover maps for Sub-Saharan Africa



Source: Study based on European Space Agency datasets.[128]

Table 7: Land cover extent, equivalent biomes and ecosystem services value coefficient for Sub-Saharan Africa

Land cover	Area (million ha) 1992	2000	2015	Equivalent biome	ESV (US$ ha^{-1} $year^{-1}$)
Cropland	425	439	445	Cropland	5568
Evergreen forest	203	200	198	Tropical forest	5263
Deciduous forest	447	445	453	Tropical forest	5263
Shrubland	470	461	450	Woodlands	1588
Grassland	298	299	299	Grasslands	2872
Wetland	46	47	47	Inland wetlands	25,681
Urban	2	2	4	Urban	–
Bareland	444	444	439	Desert	–
Waterbodies	30	30	30	Rivers/lakes	4267

Source: Fenta et al. (2020)[129]. The ESV coefficients were derived from de Groot (2012) and Costanza et al. (2014)[130]

In this report we quantified the economic values of the four primary ecosystem services—provisioning, regulating, habitat, and cultural—using the value transfer approach (de Groot et al. 2012). The value of the ecosystem services represented by each land cover type was derived by multiplying the land area to be restored by the ESV coefficient. Table 8 indicates that restoring 175 million ha of land by 2050 would yield $1.1 trillion in ecosystem services by 2050, or $35.32 billion annually.

Table 8: Ecosystem Services Value of Land Restoration in Sub-Saharan Africa by 2050

Land cover	Extent in 2015 (M ha)	Degraded proportion	Degraded Area (M ha)	Degraded Area to be Restored (M ha)	ESV coefficient ($ ha -1 year -1)	In 2007 $ M	In 2021 $ M	ESV Proportion
Cropland	445	12%	53.40	19.15	5,568	106,625	140,745	13%
Evergreen Forest	198	26%	51.48	18.46	5,263	97,161	128,252	12%
Deciduous Forest	453	26%	117.78	42.24	5,263	222,292	293,425	28%
Woodland	450	28%	126.00	45.18	1,588	71,753	94,714	9%
Grassland	299	40%	119.60	42.89	2,872	123,178	162,595	15%
Wetland	47	42%	19.74	7.08	25,681	181,793	239,967	23%
			488.00	175.00		802,801	1,059,698	100%

Sources: Fenta et al (2020). Degraded proportion was derived from Le et al. (2014), and ESV coefficients from Costanza et al. (2014). Degraded area to be restored for each land cover was derived by multiplying its degraded area by 175 million ha and dividing by 488 million ha (the total degraded area). Given that the coefficients were derived in 2007 dollars, a factor of 1.32 was used to convert to 2021 dollars.

Climate information services. The cost of inaction from CIS was estimated as the avoided economic losses from the provision of early warning services for farmers and land managers (Hallegate et al. 2016; Hallegate et al. 2017). Risk assessment was conducted for countries considering the various dimensions of inequality of poor and non-poor people in the face of disasters and the distribution of losses across individuals. The analysis considered the different abilities of poor and non-poor people to cope with asset losses by modeling the effects of asset losses on income (accounting for capital productivity and diversification of income sources) and consumption (accounting for savings, remittances, and social protection, and post-disaster transfers). Consumption losses were translated into well-being losses, considering the different impacts of a $1 loss on poor and non-poor individuals. Well-being loss at the country level depends on the distribution of impacts within the population, but it is expressed as the equivalent loss in national consumption. Socioeconomic resilience measures an economy's ability to minimize the impact of asset losses on well-being, and was defined as the ratio of asset losses to well-being losses:

$$\textbf{socioeconomic resilience} = \frac{\text{asset losses}}{\text{well-being losses}}$$

Risk to well-being combines hazard, exposure, asset vulnerability, and socioeconomic resilience using the equation

$$\textbf{Risk to well-being} = \frac{\text{expected asset losses}}{\text{socioeconomic resilience}} = \frac{(\text{hazard}) * (\text{exposure}) * (\text{asset vulnerability})}{\text{socioeconomic resilience}}$$

Figure 3: Socioeconomic resilience

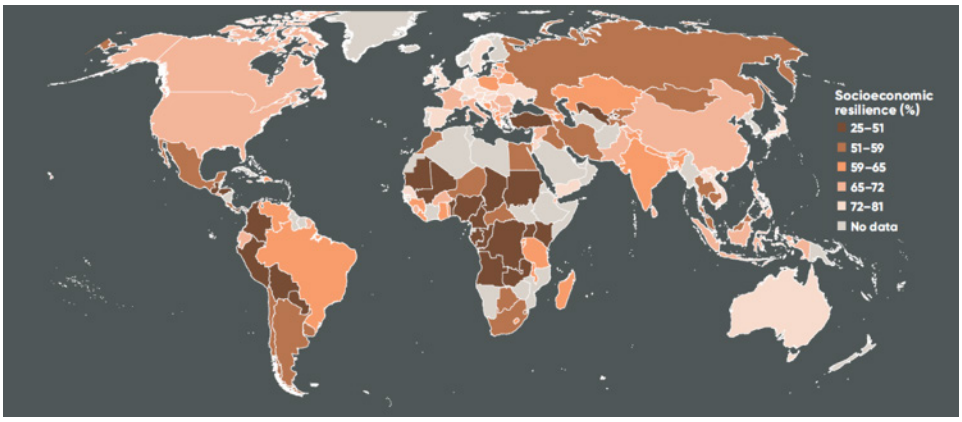
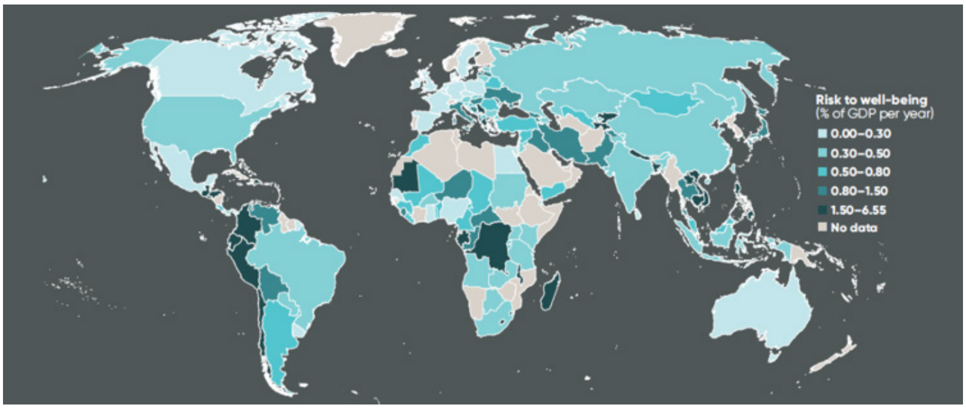


Figure 4: Risk to well-being as percentage of GDP per year



The economy-wide annual avoided asset and well-being losses from the provision of early warning systems from the studies above are available for 32 Sub-Saharan countries. The simulations evaluated the benefits of providing universal access to early warning systems globally, assuming that state-of-the-art warnings can reduce asset losses by up to 20% on average. The estimated avoided losses were multiplied by the average agriculture contribution to GDP for each country from 2015–2020 to derive the avoided losses to agriculture sector (Figure 5). The average value of about $10.6 million was multiplied by 46 to derive the annual avoided losses for Sub-Saharan Africa of $488.6 million, totalling up to $14.7 billion by 2050.

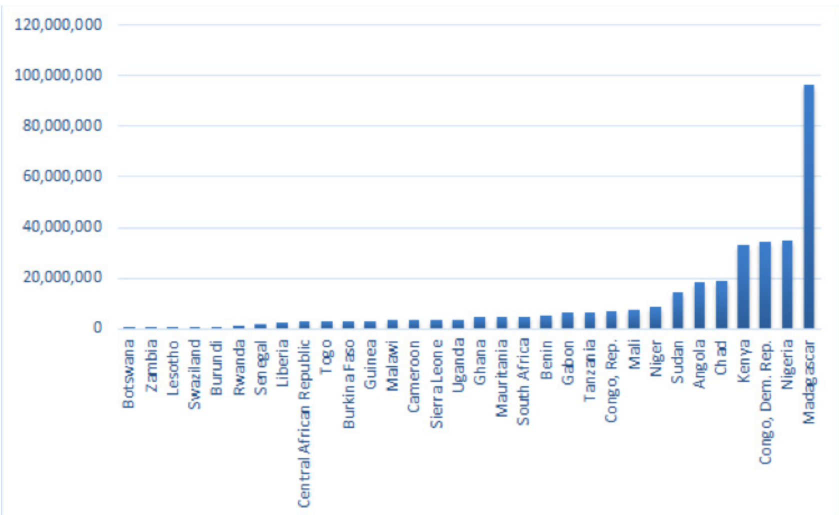


Figure 5: Avoided annual losses from the provision of CIS for agriculture ($)

Source: Agriculture sector– specific computations based on Hallegatte et al. (2017)

Economic activity in a month can shrink by 1 percent when the average temperature is 0.5°C above normal. This impact is 60 percent larger than the average for emerging market and developing economies in other regions, reflecting Sub-Saharan Africa's agricultural dependence and the temperature sensitivity of its agricultural sector. Climate-induced natural disasters, especially droughts, have a long lasting impact on agroecosystems and people depending on them, reflecting the prolonged nature of the disasters. For example, medium-term annual economic growth in Africa can decline by 1 percentage point with one additional drought. This impact is about eight times that in emerging markets and developing economies in other regions.

Challenges to economic growth are compounded by widening fiscal and current account deficits and corresponding pressures on public debt and international reserves after a natural disaster. Reduced economic activity translates into lower tax revenues, while spending needs accelerate with the demands of post-disaster relief and humanitarian support and rebuilding damaged infrastructure. Post-disaster foreign financial assistance or remittances seldom fully offset strains on external positions from reduced agricultural exports and increased imports for reconstruction. Financial system stability can also be affected by rapid increases in non-performing loans and deposit withdrawals for banks and deteriorated balance sheets for insurance companies. More broadly, assets stranded because of weather-related disasters could lower collateral values and hurt the stability of financial institutions.

Table 9: Annual agricultural adaptation costs and costs of inaction ($ billion)

	Research and extension	Water management	Infrastructure and market access	Sustainable Land Management	Climate information services	Total
Cost of action ($ billion)	3.88	6.12	2.08	3.35	0.053	**15.48**
Cost of inaction ($ billion)	71.21	90.67	12.56	26.76	0.488	**201.69**
Cost of action as proportion of cost of inaction (%)	5.44	6.75	16.56	12.51	10.86	**7.67**

Sources: Based on Nkonya et al. (2016); Alene et al. (2010); Fenta et al. (2020); Fuglie (2018); Nin Pratt (2021); Venton et al. (2019); Ludwig et al. (2016); and various calculations

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