Climate Change and Economic Development in Africa

Senior Policy Seminar XXIV

Bringing Rigour and Evidence to Economic Policy Making in Africa

AFRICAN ECONOMIC RESEARCH CONSORTIUM

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Climate Change and Economic Development in Africa

AERC Senior Policy Seminar XXIV

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Seminar Papers

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About African Economic Research Consortium (AERC)

African Economic Research Consortium, established in 1988, is a premier capacity building institution in the advancement of research and training to inform economic policies in sub-Saharan Africa. It is one of the most active Research and Capacity Building Institutions (RCBIs) in the world, with a focus on Africa. AERC's mission rests on two premises: First, that development is more likely to occur where there is sustained sound management of the economy. Second, that such management is more likely to happen where there is an active, well-informed cadre of locally based professional economists to conduct policy-relevant research. AERC builds that cadre through a programme that has three primary components: research, training, and policy outreach. The organization has now emerged as a premier capacity building network institution integrating high quality economic policy research, postgraduate training, and policy outreach within a vast network of researchers, universities, and policy makers across Africa and beyond. AERC has increasingly received global acclaim for its quality products and services and is ranked highly among global development think tanks.

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Abbreviations

ACET	African Center for Economic Transformation
AERC	African Economic Research Consortium
AEZs	Agro-Ecological zones
AGSP	African Green Stimulus Programme
AMCEN	African Ministerial Conference on the Environment
ASTI	Agricultural Science and Technology
AU	African Union
BAU	Business-As-Usual
CAPEC	Cellule d'Analyse de Politique Economique du CIRES
CC	Climate Change
CCEDA	Climate Change and Economic Development in Africa
CDM	Clean Development Mechanism
CEEPA	Centre for Environmental Economics and Policy in Africa
CERDI	Centre d'Études et de Recherches sur le Développement International
CGE	General Equilibrium
CNRS	French National Center for Scientific Research
CO2	Carbon dioxide
COVID-19	Coronavirus disease 2019
CSA	Climate-Smart Agriculture
CSO	Central Statistical Office
CTF	Clean Technology Fund
DATs	Digital Agricultural Technologies
EGH	Elder of the Order of the Golden Heart
FAO	Food and Agricultural Organization
FE	Fixed Effects
GAEZ	Global Agro-Ecological Zones
GCF	Global Climate Fund
GDP	Gross Domestic Product
GGWI	Great Green Wall Initiative
GHSs	Green House Gases
GIC	Growth Incidence Curves
GIMPA	Ghana Institute of Management and Public Administration
GNI	Gross National Income
GTAP	Global Trade Analysis Project
H.E.	His Excellency
ICT	Information, and Communication Technology
ICT	Information Communication Technology
IET	International Emissions Trading
IHS	Integrated Household Survey
ILO	International Labour Organization
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
NORAD	Norwegian Agency for Development Cooperation
OLS	Ordinary Least Squares estimator

P&I	Poverty, and Inequality
RCBIs	Research and Capacity Building Institutions
REDD	Reduction of Emissions from Deforestation and Degradation
SCCF	Strategic Climate Finance
SDGs	Sustainable Development Goals
SDGs	Sustainable Development Goals
SPS	Senior Policy Seminar
SREP	Scaling Up Renewable Energy Program
SSA	Sub-Saharan Africa
TFP	Total Factor Productivity
UN	United Nations
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USA	United States of America
VAR	Vector autoregressive
VCOs	Voluntary Carbon Offsets
WB	World Bank
WDI	World Development Indicators
WHO	World Health Organization
WTP	Willingness To Pay
ZEPARU	Zimbabwe Economic Policy Analysis and Research Unit

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Preface

The African Economic Research Consortium (AERC) convenes Senior policy seminars to provide high level African policy makers the opportunity to come together to dialogue on the results of research conducted by AERC and its affiliates, exchange policy experiences and interact with the researchers in an atmosphere of peers. The themes of these seminars are selected based on topicality and contemporary interest to African policy-making.

AERC Senior policy seminars are forums where policy makers and researchers engage in uninterrupted deliberations on a set of important issues considered significant to policy making in Africa. The seminar format insulates the policy makers from pressures related to their responsibilities and thus, creates an environment for lively professional discourse on the selected issue. Aside from the specific aims of bringing researchers and policy makers together, the seminars are directly useful to AERC because they help identify research imperatives crucial to transforming Africa. They also improve prospects for policy involvement of the researchers and enhance AERC's visibility in the policy community. Consequently, serving to highlight the growing capacity in the region for policy research and, overall, provide important feedback to AERC for its research and training programmes.

Exchange of country-specific experiences is particularly important in these seminars. The policy makers are normally identified for their interest in policy research issues and the level of seniority of the policy makers is generally high, leading to detailed discussions. Researchers are reasonably well balanced between Anglophone and Francophone, and attendance by Francophone policy makers is always encouraged.

Policy makers report that they have found their experiences in the seminars very useful. The information exchanged helps them update their knowledge on current research and sieve out issues that are relevant to their duties. Some have even been embarrassed to find out that during negotiations with international financial institutions, they have agreed to certain policies without understanding the full implications of the policy package. Seminars of this kind, while not intended or able to make the policy maker an economist, nevertheless afford the opportunity of considering the wider ramifications of their policy decisions.

AERC is hugely indebted to Honourable Peter Munya, EGH, Cabinet Secretary, Ministry of Agriculture, Livestock and Fisheries, Kenya, who was the Guest of Honour at the official opening of the Seminar and delivered a keynote speech. The speech was read on his behalf by Mr. Lawrence Omuhaka, who is the Chief Administrative Secretary. The welcoming remarks were by Prof. Njuguna Ndung'u, AERC Executive Director. The conference was also graced by Hon. Mthuli Ncube, Minister for Finance and Economic Development, Zimbabwe; Dr. Denny Kalyalya, Governor, Bank of Zambia; Dr. Adelaide Matlanyane, former Governor, Central Bank of Lesotho; Dr. Anthony Maruping, Former Commissioner for Economic Affairs, African Union Commission and H.E. Dr. Kheswar Jankee, Ambassador of Mauritius in Russia, among other high level policy makers.

A total of 397 participants from 43 countries across Africa, including high level policy makers in the rank of ministers, permanent secretaries, members of parliament, executive directors, former ministers, governors of central banks, managing directors of research institutions, among other dignitaries, participated. This was drawn from a total number of 1,126 who had registered on the virtual platform.

The conference featured four presentations by thought leaders on the theme *Climate Change and Economic Development in Africa*. Climate change has emerged as one of the key socio-economic and developmental challenges confronting policymakers in Africa, with the potential for reversing the significant gains made in poverty reduction and inequality, social inclusion, economic growth, and development in the last two decades. We notice supply side shocks that drive domestic food and energy prices are critical to this thinking and the mitigation process. This seminar helped policymakers, and other actors to better understand the impact of climate change on economic development, particularly focusing on policies that will build and strengthen the resilience of sub-Saharan African economies to ensure sustainability of growth and development.

Session One was on *Climate Change and Agriculture: Challenges, Opportunities and Policy Options,* presented by Prof. John Asafu-Adjaye, from African Center for Economic Transformation & School of Economics, University of Queensland, Australia. This session was chaired by Dr. Adelaide Matlanyane, Former Governor, Central Bank of Lesotho. The paper was discussed Prof. Wisdom Akpalu, Ghana Institute of Management and Public Administration (GIMPA), Ghana. Session Two was on *Climate Change, Poverty, Inequality and Covid-19: Avoiding the Worst Impacts,* presented by Prof. Rashid Mekki Hassan, from Centre for Environmental Economics and Policy in Africa, South Africa. This session chair was H. E. Dr. Kheswar Jankee, Ambassador, Embassy of Mauritius in Russia and the paper was discussed by Prof. Makochekanwa Albert, University of Zimbabwe.

The Third Session was on *Energy and Climate Change: What Policy Options Exist?* This session was chaired by Dr. Denny Kalyalya, Governor, Bank of Zambia. The paper was presented by Prof. Mahamady Ouédraogo, University Clermont Auvergne CNRS, CERDI, France. The discussant for the paper was Prof. Edwin Muchapondwa, from University of Cape Town, South Africa. The fourth paper was on *Urbanization and Climate Change Vulnerability: What Next?* This session was chaired by Dr. Anthony Maruping, former Commissioner for Economic Affairs, African Union Commission. The paper was presented by Prof. Kamgnia Bernadette Dia, from CAPEC, Côte d'Ivoire. This paper was discussed by Dr. Gibson Chigumira, Executive Director, Zimbabwe Economic Policy Analysis and Research Unit (ZEPARU). The presenters produced high-quality papers, and the participants were very active, thus enabling us to produce the seminar's policy recommendations that were shared with other African policy makers who did not find time to take part in this important event.

We are grateful to all those who made the seminar a great success, in particular Prof. Abebe Shimeles, Director of Research (AERC) and Prof. Théophile Azomahou, Director of Training (AERC), who made valuable inputs into the preparation and implementation of the seminar. In equal measure, AERC very much appreciates the hard work of Senvy

Maistry, Chief Communications Officer; Dr. Charles Owino, Publications Manager; Joel Mathia, ICT Administrator, and Lancer Wao, Communications and Publications Assistant in organizing the event. AERC also acknowledges with thanks Dr. Tom Kimani, Manager Training and Dr. Mark Korir, Manager Training for their role as rapporteurs, as well as Pamela Kilwake and Anne Kimani, who assisted with logistics. To these individuals, and the many others who were involved, AERC extends its heartfelt appreciation.

Prof. Njuguna Ndung'u
Executive Director
African Economic Research Consortium

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Climate Change and Agriculture: Challenges, Opportunities and Policy Options

John Asafu-Adjaye

Introduction

Although Africa accounts for less than 3% of the world's total greenhouse-gas emissions, it will bear the brunt of climate change. The region is already experiencing more frequent climate-induced natural disasters, hotter weather, erratic rainfall, and rising sea levels. The latest report from the Intergovernmental Panel on Climate Change projects likely warming of greater than 3°C by the end of this century, and there will be declining rainfall levels and more intense rainfall that will lead to widespread flooding in many areas. Climate change therefore has adverse implications for Africa's development, from health systems to agriculture, ecosystems, water resources, energy resources and physical infrastructure and threatens the achievement of the Sustainable Development Goals (SDGs).

The sector that will be hardest hit is agriculture due to its dependence on rainfall. Seven out of 10 Africans depend on agriculture for their livelihoods. It accounts for about a quarter of the GDP of African economies on average, and as much as 50% in some countries. Africa's ecosystems are also vulnerable. Climate change is already damaging terrestrial ecosystems and has considerably reduced biodiversity, in turn constraining the livelihoods of forest-dependent communities. Ocean acidification and warming are damaging ocean ecosystems, particularly coral reefs. Other climate-related stressors projected to affect coastal systems include sea level rise, flooded river deltas and increasing migration from the interior to coastal cities due to the increased frequency of drought. Africa's vulnerability to climate change is further exacerbated by other factors such as poverty, governance, and institutional challenges; and limited access to capital, including markets, infrastructure, and technology.

The climate crisis is occurring at the same time as two other megatrends—rapid population growth and urbanization. According to recent estimates, countries in Sub-Saharan Africa (SSA) could account for over half of the world's population growth between 2019 and 2050—with a projected addition of more than 1 billion people—and this trend is expected to continue until the end of the century. Urbanization across Africa has reached the levels of other regions and has continued to grow at a rate of nearly 4%. The level of urbanization in Africa is expected to reach 65% by 2050. While there were only two African cities with more than a million inhabitants in 1950, this increased to 50 in 2010 and is expected to nearly double by 2025. These factors will combine with climate change to put additional pressure on the supply of natural resources such as food, water, energy, and ecosystems.

This synthesis paper draws from studies conducted under AERC's Norad-funded collaborative research project on Climate Change and Economic Development in Africa (CCEDA). The studies utilize a combination of different data types (primary level, secondary level, national level, and aggregate) and estimation strategies to put forward empirical evidence to show that technological innovations such as climate-smart agriculture (CSA) can be harnessed to lift farm productivity and mitigate the adverse economic impacts of climate change in Africa.

The remainder of the paper is organized in the following fashion. Section 2 sets the discussion in context by briefly reviewing the impact of climate change on African agriculture. The third section provides highlights of the analytical approaches used, while Section 4 presents the main findings. The paper concludes with a discussion of the main policy implications.

The impact of climate change on African agriculture

Several studies predict negative impacts of climate change on Africa's economy and in particular agriculture. Using the dynamic GTAP model, Asafu-Adjaye (2014) estimates that climate change will negatively impact all economies across Africa. Southern Africa will be the hardest hit, with the decline in agricultural productivity reducing growth by 6 percentage points per year by 2050, followed by North Africa (-1.4 percentage points) and East Africa (-0.6 percentage points). Fischer et al. (2005), using the FAO/IIASA Agro-Ecological Zones model and climate variables from five different GCMs under four emissions scenarios, have projected that by the 2080s, climate change will cause a significant reduction in suitable rain-fed land, thereby reducing the production potential for cereals. The study shows that wheat production is likely to disappear from Africa by the 2080s. Local level assessments also indicate substantial crop losses for various countries. Stige et al. (2006) have projected significant reductions in maize production in southern Africa under possible increased ENSO conditions, assuming no adaption.

In Egypt, climate change could decrease national production of many crops (ranging from –11% for rice to –28% for soybeans) by 2050, compared with their production under current climate conditions (Abou-Hadid, 2006). Schlenker and Lobell (2010) have estimated that by 2050, maize, sorghum and millet production on the continent could decline by 22%, 17% and 17%, respectively. More recent work indicates that even at low (+2°C) levels of warming, agricultural productivity is likely to decline across the globe but particularly across tropical areas (Challinor et al., 2014). Thornton et al. (2011) estimates that, with 4°C of warming, crop seasons in most of Sub-Saharan Africa could shrink by 20% or more. In the cocoa and coffee growing areas in the tropics, temperature shifts are likely to change the distribution and reduce the productivity of the crops (Schroth et al., 2016).

Livestock is an important component of African agriculture, and approximately 80% of the potential cropland is also used for grazing. The impact of climate change on livestock farming in Africa has been examined by Seo and Mendelsohn (2007). They considered various scenarios including a uniform increase in temperature of 2.5 and 5.0°C and a uniform change in rainfall of 215% and +15% across all of Africa. Their model predicts a 32% loss in expected net revenue with a 2.5°C warming, and a 70% loss with a 5°C warming. Rainfall effects were found to be relatively smaller. For example, a 15% increase in rainfall leads to a loss of 1% in expected net revenue per household from livestock and a 15% decrease in rainfall leads to a gain of 2%. In more recent work, Rojas-Downing et al. (2017) conclude that livestock production will be limited by climate change because animal water consumption is expected to increase by a factor of three, while demand for crop land (which accounts for a significant share of livestock feed) will increase due to increased food demand.

Cline (2007) conducted one of the most comprehensive analyses of the impacts of climate change on global agriculture through the 2080s. Using a Ricardian model, he predicts declines in agricultural output for all the African countries in the sample. The losses are reduced to some extent in countries with a significant share of cropland under irrigation. The weighted average crop losses for a Business-As-Usual (BAU) scenario without carbon fertilization range from 84% (Senegal) to 2.5% (Uganda), with a mean decline of 27.8% for the sample. Countries such as Sudan, Senegal, Niger, and Mali which have low proportions of irrigated land are projected to suffer declines of 100%, while losses of 50% or more are reported for countries such as South Africa and Zambia. Cline also used crop model forecasts, which showed similar trends as the Ricardian model forecasts. He estimates that BAU climate change by the 2080s will reduce agricultural production by about 28% on average without carbon fertilization. With carbon fertilization, the crop losses are lower, with productivity declining by 18% on average.

More recent work by Hertel et al. (2010) confirms the devastating effect of climate change on African agriculture. Based on a synthesis of the literature on regional crop yield responses to climate changes, they estimate the productivity decline in the production of selected food crops to range from 10-22% for several African countries under various scenarios. Climate change is estimated to impact more severely on South Africa where decline in the production of coarse grains is projected to decline from 25-42% (Hertel et al., 2010).

Analytical framework

Various modelling strategies were employed to investigate the effects of climate change on African agriculture. Although we feature below an econometric (panel vector-auto regression) model by Ebeke and Etoundi (2021) and a computable general equilibrium (CGE) model by Asafu-Adjaye (2021). Discussion of the results and policy implications incorporate findings from Phiri et al. (2021), Hailemariam (2022) and Tione et al. (2021).

The panel vector-auto-regression (VAR) model and data

The following reduced-form panel vector-auto-regression (VAR) model was specified:

$$a_{it} = (\theta_1 + \theta_2 Z_{it-5})\, Shock_{it} + \theta_3 Z_{it-5} + X'_{it}\beta + u_{i.} + \gamma_t + \epsilon_{it} \qquad [1]$$

where a denotes the rolling standard deviation of the residuals of the growth rate of crop yield derived from a stochastic and quadratic trend observed in a country i, over a period of 5 years t. Country-specific fixed-effects (u_i) in the model control for all time-invariant or very slow-moving factors that drive agricultural productivity growth or its instability. These could be geographical factors (land ruggedness, country's latitude, quality of governance). Time fixed effects (γ_i) are controlled for to account for common shocks to countries at each given year. These, for example, are related to fluctuations in commodity prices (such as oil prices).

The other model variables are as follows:

(i) Agricultural productivity in the model is measured by the level of crop yield (crop production per hectare harvested) and data for that were from the Food and Agricultural Organization's database.

(ii) *Shock* is the climate instability variable derived by computing the five-year rolling standard deviation of the rainfall residuals derived from country-specific stochastic and quadratic trends. Time series of average annual rainfall in millimeters are drawn from the World Bank's Climate Change and Knowledge Portal.

(iii) The variable *Z* represents the set of conditional factors in the climate-agricultural productivity nexus. It enters the model with a four-year lag to account for the fact that variables such as innovation, infrastructures or access to finance take some time to have an impact on agricultural productivity. The set of variables is chosen to assess the impact of *proximal* factors that act immediately on resilience such as agricultural innovation, irrigation, and infrastructure.

(iv) Agricultural innovation is measured using the following proxies: Agricultural Science and Technology (ASTI) spending as a percentage of agricultural value added; the ASTI researchers per 100,000 farmers; and the consumption of fertilizers in agriculture in kg per hectare and in logs. The former two variables are extracted from the FAO statistical database while the latter is drawn from the World Bank tables. *À priori*, we expect these variables to reduce the sensitivity of crop productivity instability to climate instability in Africa. That is, we first expect climate shocks to positively affect productivity instability (i.e., θ_1 to be positive). Next, we expect that this positive effect would be dampened by agricultural innovation (i.e., θ_2 to be negative).

(v) Irrigation was measured using the log share of agricultural land that is irrigated, with the data coming from the World Bank's World Development Indicators database.

(vi) To ensure that the model is well specified, the lagged level of economic development proxied by the log of per capita GDP was also controlled for.

The CGE model

The Global Trade Analysis Project (GTAP) computable general equilibrium model (Hertel et al., 1997) model was used to analyze the impacts of climate change on African agriculture. The version of the GTAP model applied in this study is the GTAP-AEZ model which facilitates more comprehensive analyses of the trade-offs due to climate change, alternative land use, and land-based mitigation strategies in an economy-wide framework (e.g., see Hertel et al., 2009). It also considers land rent effects and the impacts on land use via factor market effects. The land-use database disaggregates land endowment and the three land-use activities (cropland, grazing land, and forest) into 18 global agro-ecological zones (AEZs) based on six different lengths of growing periods (6 x 60-day intervals), and three climatic zones (tropical, temperate, and boreal) (Monfreda et al., 2009).

For this analysis, we used the land-use augmented version of the GTAP 8. We combined the original 113 GTAP regions into 15 regions including Sub-Saharan Africa. North Africa is aggregated with the Middle East given the similarities in their AEZs. Furthermore, the original 57 GTAP commodity sectors were aggregated into 14 sectors to facilitate the analysis (see Table A3).

To simulate climate-induced productivity shocks, we took estimates from Hertel et al. (2010) in preference to others such as Knox et al. (2012) and Laborde (2011) because it has a wider coverage of crops. We considered two crop productivity scenarios: (1) the 'most likely' or 'central case' which we refer to as the 'medium crop productivity scenario' and (2) an 'extreme case' which we refer to as the 'low crop productivity scenario'. The latter assumes a world with rapid temperature change, a high sensitivity of crops to warming, and a CO_2 fertilization effect at the lower end of published estimates. The assumed climate-induced output augmented technical change reflected in the percentage of crop productivity changes in major crop sectors are shown in Table 1 below. These climate-induced productivity shocks are used to simulate changes for all the regions in the world to compare with the results for Africa, particularly for changes in land use and the induced CO_2 emissions resulting from that. More detailed results are also analyzed for Africa given the focus of the paper.

To investigate the potential of agricultural intensification for mitigating deforestation and LCLUC-induced CO_2 emissions, we first estimated yield gaps for the selected major crops, namely, rice and maize, millet, and sorghum. For the purposes of the modelling, maize, millet, and sorghum are aggregated under 'other cereal grains'. The average yield gaps for rice and coarse grains were taken from Africa Rice Center (2013) and Tian and Yu (2019), respectively. Next, we used statistics from the Food and Agricultural Organization (FAOSTAT) and the Global Agro-Ecological Zones (GAEZ v3.0) database to calculate the linear trends of actual and potential yields for the selected crops. We then calculated the total factor productivity growth (TFP) required to close the yield gap by 50% for Sub-Saharan Africa. Finally, we used the productivity shocks to analyze the potential of increased TFP as a land-based mitigation strategy for LCLUC-induced CO_2 emissions.

Table 1: Productivity shocks considered

Region	Climate-induced Crop Productivity Changes (Measured as percentage change)											
	Low Crop Productivity Scenario						Medium Crop Productivity Scenario					
	Rice	Wheat	Coarse grains	Oil seeds	Vegetables, fruit, nuts	Other crops	Rice	Wheat	Coarse grains	Oil seeds	Vegetables, fruit, nuts	Other crops
Brazil	-10	-10	-17	-5	-10	-10	-3	-3	-10	2	-3	--3
Canada	-10	-5	-17	0	-10	-10	-3	7	-10	12	2	2
China	-12	-10	-22	-12	-15	-15	0	2	-10	0	-8	-8
EU 27	-5	-5	-17	-5	-5	-5	7	7	-5	7	7	7
Indonesia	0	0	7	0	0	0	7	7	0	7	7	7
India	-15	-10	-17	-10	-10	-10	-5	-3	-10	-3	-3	-10
USA	-10	-10	-32	-10	-10	-10	-3	2	-15	2	2	2
Rest of East Asia	5	5	-2	5	5	5	12	12	5	12	12	12
Rest of Latin America	-10	-10	-17	-10	-10	-10	-3	-3	-10	-3	-3	-3
Rest of the World	-5	-5	-17	-7.5	-5	-5	7	7	-5	4.5	7	7
Rest of South Asia	-15	-10	-17	-10	-10	-10	-5	-3	-10	-3	-3	-3
Rest of Southeast Asia	-10	-10	-17	-10	-10	-10	-3	-3	-10	-3	-3	-3
North Africa & Middle East	-5	-5	-12	-5	-5	-5	2	2	-5	2	2	2
Sub-Saharan Africa	-15	-15	-22	-15	-15	-15	-3	-3	-10	-3	-3	-3

Key findings

Panel VAR model results

We first report the first set of results (see Table 2) for the traditional fixed effects estimates. We ran the estimations variable by variable (see Columns 1 to 4) to address the expected strong collinearity between the conditional variables Z. The key results are the following:

- As expected, the coefficient of rainfall instability has a statistically significant positive effect on the volatility of crop yield.
- The interaction terms of climate instability and spending on ASTI and with the number of available ASTI researchers both have negative and statistically significant coefficients as hypothesized. These results suggest that greater investment in agricultural science and technology makes a difference by dampening the sensitivity of crop productivity to climate instability.
- We did not find a statistically significant effect of fertilizer use or irrigation in dampening the effect of climate instability on yield volatility.

Climate instability was measured in the study by computing the five-year rolling standard deviation of the rainfall residuals derived from country-specific stochastic and quadratic trends. To check the robustness of the results, we used two alternative measures of rainfall variability. The first variability measure was computed from the standard deviation over each period of 12 months of year-on-year changes in rainfall in each country to capture within-country within-year instability of rainfall changes. The second measure extracted the corresponding volume of rainfall during months with maximum rainfall (in mm) for each year and for each country to establish uncertainty (or volatility) over the volume of rainfall. The results (see Tables A1 and A2) indicate that regardless of the measure of rainfall instability used, the basic results remain unchanged.

Table 2: Impact of climate instability on crop yield instability in Sub-Saharan Africa: OLS fixed effects estimates

Variable	(1)	(2)	(3)	(4)
Rainfall instability	0.197***	0.444***	0.408***	0.216*
	(3.681)	(4.429)	(2.816)	(1.925)
Rainfall instability * (ASTI spending-to-value added, lagged)		-0.269***		
		(-4.119)		
Rainfall instability * (ASTI researchers ratio, lagged)			-0.115**	
			(-1.998)	
Rainfall instability * (Fertilizer use, lagged)				-0.0330
				(-0.793)

continued next page

Table 2 Continued

Variable	(1)	(2)	(3)	(4)
ASTI spending-to-value added, lagged		0.0440***		
		(3.767)		
ASTI researchers ratio, lagged			0.0486***	
			(3.284)	
Fertilizer use, lagged				0.00582
				(1.116)
Log of real GDP per capita, lagged	-0.008	-0.0379**	-0.0523***	-0.0737***
	(-0.543)	(-2.117)	(-2.848)	(-3.079)
Constant	0.175	0.371***	0.423***	0.667***
	(1.482)	(2.623)	(3.058)	(3.555)
Fixed effects	Yes	Yes	Yes	Yes
Observations	1,035	692	712	396
R-squared	0.0156	0.039	0.032	0.041
Number of countries	43	38	38	33

Notes:

Dependent variable: volatility of crop yield.

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

We further tested the robustness of the results by using a different estimation approach—dynamic panel data techniques. The presence of lagged dependent variables and the country-specific effects render traditional Ordinary Least Squares estimator (OLS) biased. Fixed effects (FE) estimators can eliminate the country-specific effect. However, the bias caused by the inclusion of lagged dependent variables remains. To address these problems, we used the System-GMM estimator developed for dynamic panel data by Blundell and Bond (1998). In this approach, equations in levels and the equations in first differences are combined in a system and estimated with an extended System-GMM estimator which allows for the use of lagged differences and lagged levels of the explanatory variables as instruments. In the framework, all the explanatory variables and the interaction term that includes the slow-moving variables Z, are treated as predetermined.

There are good reasons to treat climate shock variables as not strictly exogeneous in this framework. Agriculture is a major source of greenhouse gases which contribute to the greenhouse effect and therefore climate change. At the same time, it is obvious that climate change is not a localized phenomenon solely explained by human agricultural activity in each region. Put differently, climate hazards (rainfall and temperature instability) in a country i do not mostly originate from the sole activity generated in that country. This helps provide some degree of exogeneity to our climate shock variables in the model. And because the interaction terms Z also enter the equations with lags, we further reduce their endogeneity bias as well.

The results of these additional estimations (see Table 3) reinforce the earlier conclusions. First, climate instability in the form of rainfall instability increases the volatility of crop yield in Africa. However, greater investment in ASTI can dampen the effect of climate shocks on crop yield productivity.

Table 3: Impact of climate instability on crop yield instability in Sub-Saharan Africa: Dynamic GMM estimates

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Rainfall instability	0.551***	0.481**	0.0836	-0.243
	(3.110)	(2.152)	(0.360)	(-1.011)
Rainfall instability * (ASTI spending-to-value added, lagged)	-0.398**			
	(-2.430)			
Rainfall instability * (ASTI researcher ratio, lagged)		-0.200**		
		(-2.116)		
Rainfall instability * (Fertilizer use, lagged)			0.0372	
			(0.303)	
Rainfall instability * (Irrigation, lagged)				-0.0354
				(-1.541)
ASTI spending-to-value added, lagged	0.0600***			
	(2.675)			
ASTI researcher ratio, lagged		0.0330**		
		(2.404)		
Fertilizer use, lagged			-0.000756	
			(-0.0666)	
Irrigation, lagged				0.00102
				(0.330)
Lagged volatility of crop yield	0.908***	0.868***	0.892***	0.422***
	(16.78)	(23.06)	(18.37)	(4.215)
Log of real GDP per capita, lagged	0.00399	-0.000976	0.00142	0.0619***
	(1.195)	(-0.119)	(0.493)	(2.848)
Constant	-0.0888**	-0.0507	-0.0153	-0.372**
	(-2.067)	(-0.826)	(-0.426)	(-2.531)

continued next page

Table 3 Continued

Variable	(1)	(2)	(3)	(4)
Observations	690	710	396	95
AR[2]: p-value	0.512	0.451	0.016	0.520
Hansen OID: p-value	0.285	0.451	0.546	0.602
No of instruments	21	21	21	21
Number of countries	38	38	33	21

Notes:

Dependent variable: volatility of crop yield.

t-statistics in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

CGE model results

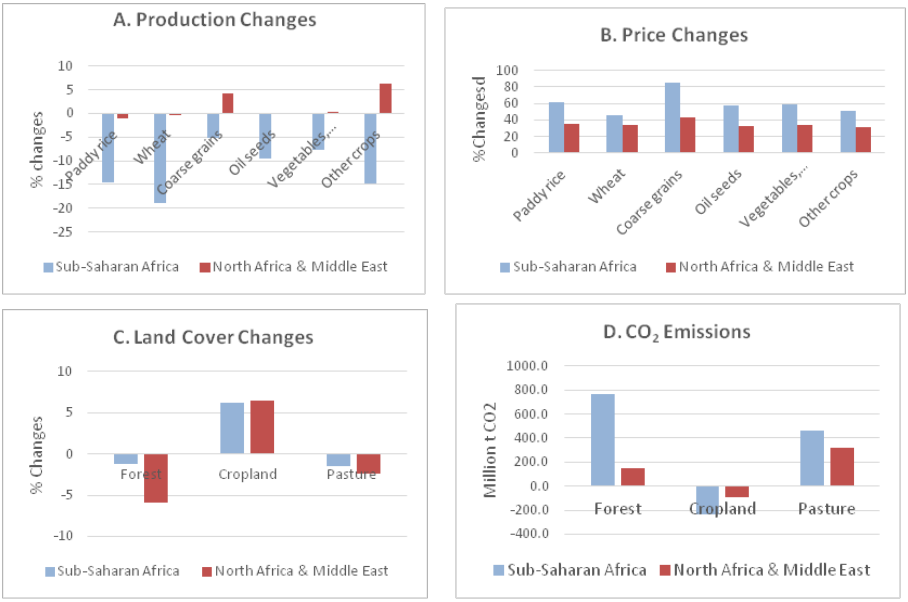
Impacts of climate change on agriculture and land use

Here we report results for the impacts of climate change for only the low crop productivity scenario. As expected, there are production declines across all crops for Sub-Saharan Africa in 2030 (Figure 1A). The declines range from -5% (coarse grains) to -19% (wheat). The production declines are much less for North Africa and the Middle East and some crops such as coarse grains and other crops see an increase in output. The output reductions lead to increase in local prices by more than 50% across all crop types with prices for coarse grains in Sub-Saharan Africa rising by as much as 86% (see Figure 1B). Prices also rise for North Africa and the Middle East but to a lesser extent. The reduction in output means that domestic food production must be supplemented by imports.

The higher agricultural prices make production more profitable, causing factor inputs to be drawn away from other activities. Therefore, we observe an expansion of cropland by more than 5% in both Sub-Saharan Africa and North Africa and the Middle East at the expense of shrinking forest and pasture lands (see Figure 1C), resulting in deforestation across the continent. The expansion of croplands in Africa is driven entirely by the increases in the harvested area of rice, wheat, and coarse grains.

At the global level, the low crop productivity scenario causes substantial increases of cropland use of 62.3 Mha and this is compensated entirely from pasture lands, enabling some reforestation of 2.5 Mha. Figure 1D shows that because of the cropland expansion and regional deforestation, CO2 emissions increase in Sub-Saharan Africa by 766 million t CO2, while they increase by 151 million t CO2 for North Africa and the Middle East. There are also increase in CO2 emissions from pastures. However, the emissions are offset to some degree by reductions of 236 and 89 million t CO2 from croplands for Sub-Saharan Africa and North Africa and the Middle East, respectively.

Figure 1: Impacts of climate-induced low crop productivity on agriculture and the environment in Africa



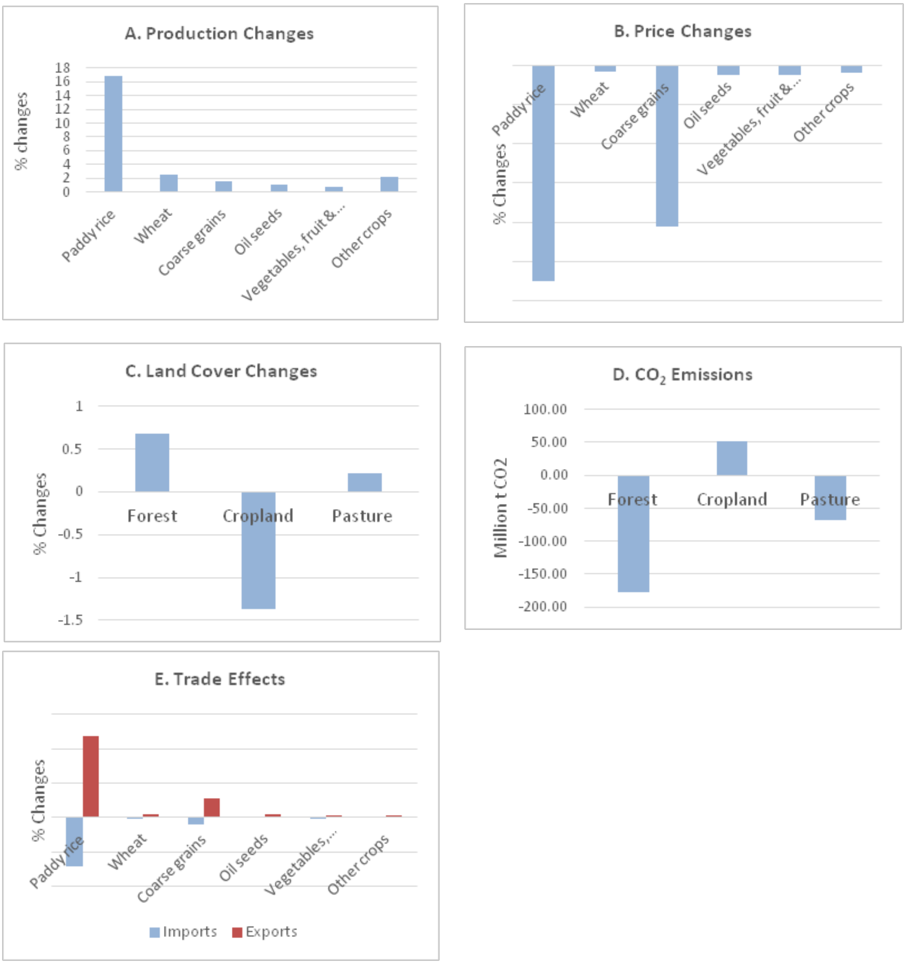
Source: GTAP model simulations.

Mitigating climate change effects through improvements in productivity growth

In this policy experiment, we examine the possibility of mitigating the adverse impacts of climate change by increasing TFP to close the yield gap for two major crop types—paddy rice and coarse grains. We track the effect of the policy on production, prices, land-use changes, LCLUC-induced emissions, and trade. Starting with production, with the productivity improvement, there are production increases for all crop types. Paddy rice, wheat, and coarse grain production increase by 17%, 3% and 2% respectively (Figure 2A). In line with this trend, we observe reductions of 28%, 1% and 21% in the respective prices (Figure 2B).

The productivity improvement leads to increased land cover from forests and pastures, while landcover from crops decline (Figure 2C). The forestry reversion and other land-use changes associated with TFP growth reduces LCLUC-induced CO2 emissions by 246 million t CO_2 in Sub-Saharan Africa (Figure 2D).

Figure 2: Impacts of productivity growth on agriculture and the environment in Sub-Saharan Africa



Source: GTAP model simulations.

This scenario shows that with technological progress, imports of key crops such as rice and coarse grains decline, while exports increase. For example, Sub-Saharan Africa's exports of paddy rice and coarse grains increase by as much as 178% and 28%, respectively, compared to the baseline scenario (Figure 2E). This leads to the region moving from being a net food importer to a net food exporter in the counterfactual scenario, contributing to a sizeable trade surplus of US$726 million. The increased productivity of primary factors and intermediate inputs also enables a saving of 16.7 Mha of cropland from being cultivated thereby increasing landcover and reducing CO2 emissions.

Results from other CCEDA studies

The foregoing studies show that technological innovations in agriculture can be leveraged to mitigate the adverse effects of climate change on African agriculture. An example of such an innovation is climate-smart agriculture (CSA) which includes the use of new crop varieties that tolerate heat and soil salinity and resist floods and drought, and the use of practices such as agricultural intensification, crop diversification, and integrated pest management. By making more effective use of land and agricultural inputs, CSA helps to reduce the amount of additional land needed for production, thereby helping to conserve land cover and reduce CO2 emissions.

Several CCEDA studies were undertaken to improve our understanding of CSA adoption across Sub-Saharan Africa and the challenges to adoption and scaling up. Phiri et al (2021) show that CSA adoption varies across agro-ecological zones for different crops cultivated and animals reared. Some common CSA technologies and practices adopted across the three countries in the study (Kenya, Malawi, and Nigeria) include crop rotation, minimum/ zero tillage, improved seed varieties, conservation agriculture, farmyard manure and agroforestry. They find that the key drivers of CSA technologies and practices include access to extension services, the age of the farmers—with younger farmers more willing to adopt CSA practices compared to older farmers, land tenure and property rights, gender, educational level of farmers and social capital, amongst others.

In a study covering Malawi, Uganda and Kenya, Tione et al. (2021) assessed the intertemporal and spatial anthropogenic changes in land use associated with CSA household decisions. They report that the average number of households allocating land and the extent of land allocated to a basket of CSA technologies has been fluctuating but with an overall negative trend in the recent past. They show that the increase in owned land is positively associated with allocating more land to CSA. However, renting land has mixed results. Where land scarcity is high, rented land is also associated with increased use of CSA technologies but where land rental markets are not active, rented land shows a negative association although this was not significant.

Hailemariam (2022) find gender gaps in adoption of CSA practices in four African countries—Ethiopia, Nigeria, Malawi, and Tanzania. The direction of the difference depends on the type of CSA practices. In Ethiopia, the adoption of CSA practices is higher on men managed plots than women managed plots with a higher gender gap on adoptions of yield-increasing and resource-conserving practices. The adoption rate is much higher on plots managed jointly by men and women than plots managed solely. In Malawi, however, adoption of CSA practices is higher on women-managed plots than men-managed plots. The gender gaps are much higher on the adoption of risk-protecting practices. Inequalities in Nigeria are also large for adoption of CSA practices, where adoption of yield-increasing and risk-reducing practices are higher on men-managed plots compared with women-managed plots. In Tanzania, the gender gap on adoption of CSA practices is relatively smaller.

Conclusions and policy implications

The studies reviewed in this paper provide comprehensive empirical support for the widely accepted view that climate change will have a devastating impact on Africa's agriculture. Given that most Africans depend on the agricultural sector for their income and livelihoods, a climate-induced decline in agricultural productivity leads to significant decline in household income and therefore a massive fall in welfare. With the decline in agricultural output, food demand will outstrip supply and put upward pressure on domestic prices and hence inflation. This will drive many African countries to become net importers of food commodities. Although poverty and food insecurity are not directly measured here, it can be inferred from the results that both will be exacerbated by climate change particularly for the vulnerable and low-income groups for whom food forms a large part of their budget. The results also show that a climate-induced decline in agricultural productivity could result in more crop land being brought under production to satisfy food demand. This will accelerate the loss in landcover as more forest land is converted into crop land, resulting in increased CO2 emissions which will, in turn, feed into more climate variability. The studies indicate that greater investment in science and technology in Africa's agricultural sector can mitigate the adverse impacts of climate change by increasing agricultural productivity, which results in less land being brought under production thereby reducing CO2 emissions.

Five key policy messages emerge from these results. First, Africa's agricultural sector requires greater government support given its role in poverty reduction and as a potential driver of economic transformation. In their 2014 Malabo Declaration, African leaders pledged to spend at least 10% of their annual budgets on agriculture. However, to date, only a handful of countries have kept their promise. Despite the high returns to African agricultural investments, Africa's agricultural expenditure as a share of total public expenditure average only 4% over the period 2000–2014 compared to 13% for East Asia and the Pacific and 8% for Latin America and the Caribbean (Goyal and Nash, 2017). There is the need for increased financial support to build the capacity of national agricultural research systems, including meteorological agencies.

Second, it was shown that the climate risk can be turned into an opportunity by leveraging innovations such as CSA to increase productivity and profitability on smallholder farms. African farmers, however, face numerous challenges in adopting CSA. Key among them is the following: access to information about CSA practices, access to credit, and access to insurance services. CSA is a knowledge-intensive intervention, but public extension systems in Sub-Saharan Africa have too few resources to serve highly scattered and heterogeneous smallholder farmers who have little formal education. To promote the diffusion of CSA, African governments should strengthen national agricultural research and extension systems to provide information on localized CSA practices to farmers.

Third, there is a need for African governments to scale up the availability, access, and affordability of digital agricultural technologies (DATs) which are the key drivers of CSA interventions. To do so will require building the requisite infrastructure and ecosystems. There will also be the need to address both the supply-side and demand-side barriers to DAT access. Measures to ease the supply-side barriers should include improving low rural network coverage and increasing farmers' access to digital applications, while the demand-side measures should include improving farmers' skills and knowledge.

Fourth, the finding that land ownership and land markets affect adoption of CSA has important implications, especially in the context of the global response to climate change. COP26 reached agreement on Article 6 of the Paris Agreement, which paves the way for a world carbon market to operate. This is a huge opportunity for Africa to leverage its massive carbon stocks and renewable energy resources to become a major player in this global market. But Africa faces major challenges with lack of capacity and poor institutions, one of which is insecure or weak land and forest tenure by farmers and communities. Urgent land reforms are needed to enable smallholder farmers and forest communities to benefit from climate finance schemes such as the Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative and carbon trading.

Finally, to improve agricultural productivity and address climate risk, there is a need for concerted efforts to end the gender disparity in African agriculture. Although women make up half of the agriculture labour force and a large share of food producers in most African countries, they face many challenges. Barriers such as access to land, credit and other inputs mean that female farmers tend to have lower output and incomes than their male counterparts. Women also have unequal access to agricultural inputs such as seeds, fertilizers and pesticides that are needed to increase productivity. Gender differences are also found in technology adoption such as the uptake of CSA practices. There is therefore the need to develop innovative policies for equalizing access to key inputs, resources, credit, and adoption of CSA technologies.

References

Abou-Hadid, A. F. (2006) "Assessment of Impacts, Adaptation and Vulnerability to Climate Change in North Africa: Food Production and Water Resources", Assessments of Impacts and Adaptations to Climate Change (AIACC) Final Report (AF 90), Washington, DC.

AfricaRice (2012) "The new Africa-wide Rice Breeding Task Force". In: *Africa Rice Center (AfricaRice) Annual Report 2011: A New Rice Research for Development Strategy in Africa.* Africa Rice Center, Cotonou, Benin, pp. 7−11.

Asafu-Adjaye, J. (2014) "Climate change and agriculture in Africa," *Journal of African Economies,* vol. 23, pp. ii17–ii49 doi:10.1093/jae/eju011.

Asafu-Adjaye, J. (2021) Addressing climate change cause and effect on land cover and land use in Africa. AERC Working Paper Series: CC-001, African Economic Research Consortium, Nairobi, September.

Blundell, R. and Bond, S. (1998) Initial Conditions and Moment Restrictions in Dynamic Panel Data Models. *Journal of Econometrics*, 87, 115−143. http://dx.doi.org/10.1016/S0304-4076(98)00009-8

Challinor, A., Watson, J., Lobell, D. (2014) "A meta-analysis of crop yield under climate change and adaptation." *Nature Climate Change*, 4, p. 287–291.

Cline, W. (2007) Global Warming and Agriculture: Impact Estimates by Country. Washington, DC: Center for Global Development and Peterson Institute for International Economics. www.cgdev.org/content/publications/detail/14090#Chpt

Ebeke, C and Etoundi, M.N. (2021) Climate instability and agricultural productivity in Africa: Cross-country evidence. AERC Working Paper Series: CC-009, African Economic Research Consortium, Nairobi, September.

Goyal, A., and Nash, J. (2017) *Reaping Richer Returns*. Washington, DC: Agence Française de Developpement and World Bank.

Hailemariam, T. (2022) Understanding the gender differences on the choice of portfolio of climate smart agricultural practices in Sub-Saharan Africa: a multi-country study. CCEDA Country Case Study, AERC, Nairobi.

Hertel, T. W., Lee, H.-L., Rose, S. & Sohngen, B. (2009) "Modeling land-use related greenhouse gas sources and sinks and their mitigation potential". In; Hertel, T. W., Rose, S. K. & Tol, R. S. J., eds., *Economic Analysis of Land Use in Global Climate Change Policy.* London and New York: Routledge.123–153.

Hertel, T. W., Burke, M. B. and Lobell, D. B. (2010) 'The poverty implications of climate induced crop yield changes by 2030', *Global Environmental Change,* 20:577–585.

Knox, J.W, Hess, T.M., Daccache, A., and Perez, O.M. (2012) What Are the Projected Impacts of Climate Change on Food Crop Productivity in Africa and South Asia? DFID Systematic Review, Final Report. Cranfield University, Cranfield, Bedfordshire, UK.

Laborde, D. (2011) Climate Change and Agriculture in South Asia: Studying Optimal Trade Policy Options. Paper presented at the Annual Meeting of the Agricultural and Applied Economics Association, Pittsburgh, Pennsylvania.

Monfreda, C., Ramankutty, N., and Hertel, T. W. (2009) Global agricultural land use data for climate change analysis. In, Hertel, T. W., Rose, S. K. and Tol, R. S. J., eds., *Economic Analysis of Land Use in Global Climate Change Policy.* London and New York: Routledge.33–48.

Phiri, A., Edewor, S.E., Charimbu, M.K. and Gaveta, E. (2021) Sustainable scaling up of climate smart agriculture techniques and practices in Eastern, Western and Southern Africa. CCEDA Country Case Study, AERC, Nairobi.

Rojas-Downing, M., Pouyan Nejadhashemi, A., Harrigan, T., Woznicki, S. (2017) "Climate change and livestock: Impacts, adaptation, and mitigation," *Climate Risk Management*, 16, 145–163.

Seo, S. N. and R. Mendelsohn (2007) 'The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis', World Bank Policy Research Working Paper 4279, Washington, DC. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2007/07/06/000016406_20070706160359/Rendered/PDF/wps4279.pdf

Schlenker, W. and Lobell, D. (2010) 'Robust negative impacts of climate change on African agriculture', *Environmental Research Letters*, Vol. 5, 014010.

Schroth, G., Läderach, P., Martinez-Valle, A. (2016) "Vulnerability to climate change of cocoa in West Africa: patterns, opportunities, and limits to adaptation". *Science of the Total Environment,* 556, p. 231–241.

Stige, L. C., J. Stave, K. S. Chan, L. Ciannelli, N. Pretorelli, M. Glantz, H. R. Herren and N. C. Stenseth (2006) 'The Effect of Climate Variation on Agro-Pastoral Production in Africa', *Proceedings of the National Academy of Science USA*, 103: 3049–53.

Thornton P., Jones P., Ericksen P., Challinor A., 2011. "Agriculture and food systems in sub- Saharan Africa in a 4°C+ world." *Philosophical Transactions of the Royal Society,* 369, p. 117–136.

Tian, X. and Yu, X. (2019). Crop yield gap and yield convergence in African countries. *Food Security*. 11:1305–1319. https://doi.org/10.1007/s12571-019-00972-5.

Tione, S.E., Kashongwe, O., Nampanzira, D., Kantengeza, and Nalule, G. (2021) Anthropogenic land-use change and scaling up climate-smart agriculture in Sub-Saharan Africa. CCEDA Country Case Study, AERC, Nairobi.

Appendix Tables

Table A1: Impact of climate instability on crop yield instability in sub-Saharan Africa: Alternative measure of rainfall variability (m)

Dependent variable: Volatility of crop yield	**(1)**	**(2)**	**(3)**	**(4)**
Rainfall instability	0.0701***	0.0414*	0.00702	0.0307
	(4.576)	(1.667)	(0.429)	(0.447)
Rainfall instability (m) * (ASTI spending-to-value added, lagged)	-0.0752***			
	(-6.179)			
Rainfall instability (m) * (ASTI researchers ratio, lagged)		-0.0243*		
		(-1.801)		
Rainfall instability (m) * (Fertilizer use, lagged)			0.00321	
			(0.595)	
Rainfall instability (m) * (Irrigation, lagged)				-0.00693
				(-0.418)
ASTI spending-to-value added, lagged	0.0857***			
	(5.837)			
ASTI researchers ratio, lagged		0.0674***		
		(3.254)		
Fertilizer use, lagged			-0.00106	
			(-0.178)	
Irrigation, lagged				-0.0231
				(-0.465)
Log of real GDP per capita, lagged	-0.0434**	-0.0588***	-0.0763***	0.0294
	(-2.474)	(-3.181)	(-3.149)	(0.413)
Constant	0.399***	0.458***	0.704***	-0.00654
	(2.863)	(3.288)	(3.747)	(-0.0119)
Fixed effects	Yes	Yes	Yes	Yes
Observations	692	712	396	95
R-squared	0.062	0.024	0.032	0.049
Number of countries	38	38	33	21

t-statistics in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Table A2: Impact of climate instability on crop yield instability in sub-Saharan Africa: Alternative measure of rainfall variability (w)

Dependent variable: Volatility of crop yield	**(1)**	**(2)**	**(3)**	**(4)**
Rainfall instability	0.0115**	0.00687	0.00210	-0.0107
	(2.014)	(1.054)	(0.276)	(-0.639)
Rainfall instability (w) * (ASTI spending-to-value added, lagged)	-0.0140***			
	(-4.309)			
Rainfall instability (w) * (ASTI researchers ratio, lagged)		-0.00389**		
		(-2.226)		
Rainfall instability (w) * (Fertilizer use, lagged)			0.000317	
			(0.119)	
Rainfall instability (w) * (Irrigation, lagged)				0.00241
				(0.750)
ASTI spending-to-value added, lagged	0.0106			
	(1.517)			
ASTI researchers ratio, lagged		0.0369***		
		(2.737)		
Fertilizer use, lagged			0.00172	
			(0.432)	
Irrigation, lagged				-0.0456*
				(-1.831)
Log of real GDP per capita, lagged	-0.0533***	-0.0640***	-0.0752***	0.0524
	(-2.958)	(-3.457)	(-3.068)	(0.765)
Constant	0.542***	0.558***	0.701***	-0.101
	(3.813)	(3.981)	(3.658)	(-0.181)
Fixed effects				
Observations	692	712	396	95
R-squared	0.046	0.031	0.029	0.055
Number of countries	38	38	33	21

t-statistics in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Table A3: Regional and Sectoral Aggregation

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
1. Brazil		1. Paddy rice	
2. Canada		2. Wheat	
3. India		3. Cereal grains nec[1]	
4. USA		4. Oil seeds	
5. Indonesia		5. Vegetables, fruit, nuts	
6. China	China, Hong Kong, Taiwan	6. Other crops	Sugar cane, sugar beet, Plant-based fibers, Crops nec.
7. Rest of South Asia	Bangladesh, Sri Lanka, Pakistan, Rest of South Asia.	7. Forests	Forestry
8. Middle East and North Africa	Egypt, Iran, Morocco, Tunisia, Turkey, Rest of North Africa, Rest of Western Asia.	8. Livestock	Bovine cattle, sheep and goats, horses, Raw milk, Wool, silk-worm cocoons.
9. Rest of East Asia	Korea Republic of, Rest of East Asia.	9. Animal products	Animal products nec
10. Rest of Southeast Asia	Cambodia, Lao People's Democratic Republic, Myanmar, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia.	10. Processed agriculture	Bovine meat products, Meat products nec, Dairy products, Processed rice, Sugar, Food products nec, Beverages and tobacco products.

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Table A3 Continued

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
11. Sub-Saharan Africa	Botswana, Ethiopia, Madagascar, Mozambique, Mauritius, Malawi, Nigeria, Senegal, Tanzania United Republic of, Uganda, South Central Africa, Central Africa, Rest of Eastern Africa, Rest of South African Customs, Rest of Western Africa, South Africa, Zambia, Zimbabwe	11. Vegetable oils and fats	
12. EU 27	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherland, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden.	12. Manufacturing	Fishing, Coal, Oil, Gas, Minerals nec, Textiles, Wearing apparel, Leather products, Wood products, Paper products, publishing, Petroleum, coal products, Mineral products nec, Ferrous metals, Metals nec, Metal products, Motor vehicles and parts, Transport equipment nec, Electronic equipment, Machinery and equipment nec, Manufactures nec.

continued next page

Table A3 Continued

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
13. Rest of Latin America	Argentina, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Panama, Peru, Paraguay, Uruguay, Venezuela, Rest of Central America, Caribbean, Rest of North America, Rest of South America	13. Chemical, rubber, plastic products	
14. Rest of the World	All the other countries not mentioned above	14. Services	Electricity, Gas manufacture, distribution, Water, Construction, Trade, Transport nec, Water transport, Air transport, Communication, Financial services nec, Insurance, Business services nec, Recreational and other services, Public administration, Defense, Education, Health, Dwellings.

Note: 1 stands for not elsewhere classified.
Source: Author's aggregation.

2

Climate Change, Poverty, Inequality and Covid -19: Avoiding the Worst Impacts

Rashid Mekki Hassan

Introduction

Achieving the sustainable development goals (SDGs), combating global warming, and containing the deadly COVID-19 pandemic are the three agenda of strategic importance for the future of life on earth currently occupying the centre of attention of the international community. Lifting the many millions of the world population out of poverty remains a hard goal to realize and the gap (inequality) between rich and poor people keeps widening (UN, 2020). At the same time, the pace and scale at which climate change and environmental degradation are unfolding pose additional threats to the prospects of achieving poverty eradication and inclusive socioeconomic development (Diffenbaugh and Burke, 2019; Lee, 2019). This is because the poor and disadvantaged are the most impacted by the adversities of global warming and consequences of disrupting the functional integrity of natural ecosystems, such as emergence of pandemics like Covid-19 (Olsson et al., 2014; CDP, 2021). Sub-Saharan Africa (SSA), being the region where poverty is concentrated and vulnerability to climate change and other natural hazards is among the highest in the world (FAO, 2018; Niang et al., 2014), presents a good example of how subtly complex the interlinkages between climate change, poverty, and inequality (P&I), and Covid-19 are.

To better understand the linkages between climate change (CC), P&I, and Covid-19, this paper addresses the following questions:

1. In what ways does CC influence the state of P&I in SSA?
2. How compatible are current global and national climate actions with achieving the goals of poverty eradication and inclusive development?
3. What links does Covid-19 have with CC and reduction of P&I?

Building on evidence from papers produced under the African Economic Research Consortium (AERC)'s "Climate Change and Economic Development in Africa (CCEDA)" Project, as well as other sources of relevant literature, this paper aims to distill and articulate key policy messages of high significance to pursuing equitable green recovery in SSA.

The next section explores impact pathways between CC and P&I and reviews some evidence of these links. Section three presents an assessment of the implications for P&I of currently conceived and implemented global actions in response to CC. Linkages between COVID-19, CC and P&I are examined in section four. The final section derives conclusions and key policy lessons and messages for a green recovery in SSA to avoid the worst of CC and the COVID-19 pandemic.

Climate change and the poor

Through its most recent assessments (Lee, 2019), the Intergovernmental Panel on Climate Change (IPCC) continues to maintain that the poor and disadvantaged "socially and geographically disadvantaged people exposed to persistent inequalities (Olsson et al., 2014)" are the most vulnerable to the adverse effects of climate change (CC). Various frameworks have been employed to analyse the relationship between CC and P&I. The hazard, exposure, and vulnerability approach are among the most common in the literature of studying impacts of CC. Hazards in this case, are the CC related shocks. Non-climatic and structural attributes (i.e., geographical location, sources of livelihoods, state of economic development, etc.) of impacted communities define the degree and nature of their exposure and vulnerability to (ability to cope with) impacts of these climate hazards.

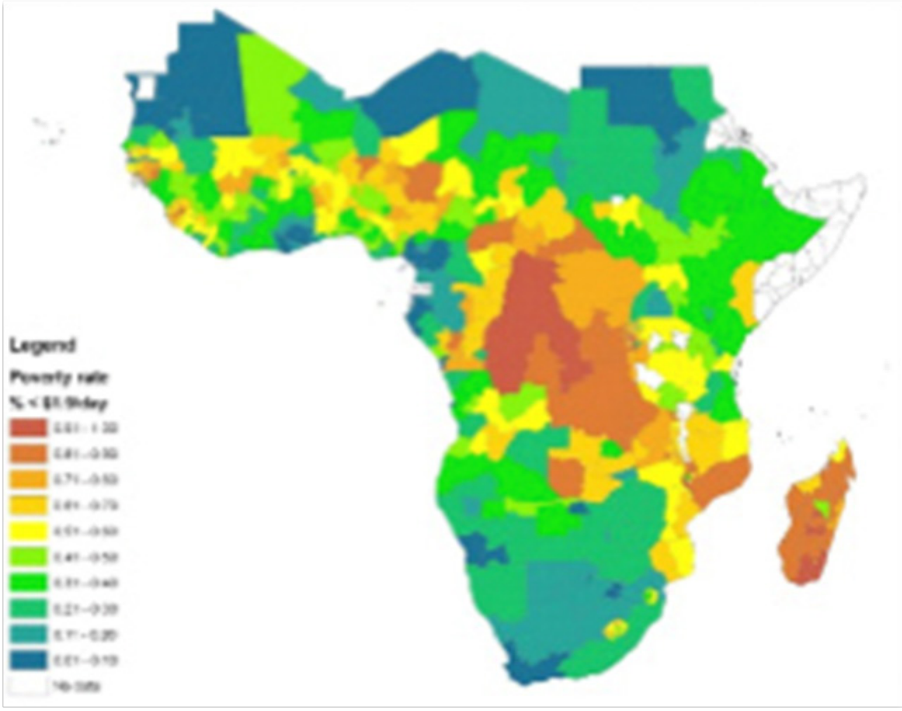
Warmer temperatures drive powerful geophysical changes in precipitation regimes, intensity, and frequency of extreme weather events (flooding, drought, storms, etc.), sea levels, among other changes, unleashing climate hazards that seriously impact all life on earth. Adverse impacts of such climate hazards include damages to infrastructure and assets, water stress and crop failures, degradation of productive land and pasture, outbreaks of diseases, and erosion of essential sources of livelihoods.

The fact that the poor concentrate in geographical regions, such as low-lying coastal zones, riverbanks and flood plains that are regularly hit by natural hazards, increase the risk of exposure to climate shocks. Statistics also indicate that 75% of the extremely poor live in marginal rural areas, where their livelihoods are highly dependent on activities sensitive to CC, such as subsistence rain-fed farming and pastoral livestock rearing systems and other direct extractions from surrounding natural resources (FAO, 2018). This obviously makes their livelihoods vulnerable to failure of rains and other climate hazards. Ability of the poor to cope with and mitigate impacts of CC hazards is severely weakened by the fact that they typically lack adequate access to basic health services, clean water and sanitation, markets, essential infrastructures for mobility, finance, insurance, and diversity of livelihoods' options.

Exposure of the poor in Africa to CC related hazards has been analysed under the AERC CCEDA project by Fisker and Taro (2021) – (F&T). Using a database of the most recent subnational household survey estimates of poverty levels aggregated to 516 administrative regions, F&T created a map depicting the spatial distribution of poverty across SSA (Figure 3). The F&T study developed an empirical model to test the hypothesis that CC hazards will occur disproportionately where the poor and vulnerable are located. To conduct the intended analysis, data on selected CC hazards (temperature and precipitation) were regressed on measures of poverty (poverty rate and number of poor) for the 516 subnational units of analysis. Two regressions were specified to estimate and test the relationship between current and future climates and poverty. Regression results did not provide strong support to the hypothesis that poverty rates are correlated with warmer and dryer climates.

These inconclusive results may be attributed to not accounting for the effects of other important CC hazards such as flooding, drought, and other CC related natural disasters. Also, sources of key structural economic vulnerabilities that are important determining cofactors are left out of the regression analysis. A good example of those is the economics of location disadvantage. The generated SSA poverty map shows some interesting spatial patterns. One discernible pattern is the apparent positive correlation between distance to the coastline and poverty, suggesting higher poverty rates in inland regions than coastal areas. Positive correlation rates of 0.35 and 0.49 were measured by F&T between distance from the coastline and poverty rates and number of poor people, respectively. This reflects the importance of structural factors such as the economic vulnerability due to location and access to trade disadvantages for poverty.

Figure 3: Distribution of poverty (poverty headcount rate < $1.90 per day) in sub-Saharan Africa (2009 and later data)



Source: Beegle and Christiaensen (2019) in Fisker and Taro (2021)

As mentioned earlier, other non-climatic determinants of vulnerability of exposed communities include structural attributes like high dependence on agriculture or primary extractive industries, limited diversity of basis of livelihoods, state of economic and institutional development, and access to markets, finance, insurance, and health services. Impacts of CC on the poor also work through important indirect pathways, especially food and energy prices. The literature documents examples of very strong associations between the said factors and CC impacts on the poor and disadvantaged. An FAO (2018) study indicated that 25% of agricultural productivity losses caused by CC related hazards have been absorbed by the rural poor. Evidence that the brunt of natural disasters is borne by the poor is found in the literature (Hallegate et al., 2020). Other examples include damages of cyclones in Madagascar (Andrianarimanana, 2015), hurricanes in Nicaragua (Herera et. al., 2018), and floods in Mumbai (FAO, 2018). Female headed households were shown to be the hardest hit among the poor by climate hazards through various impact transmission channels (Eastin, 2018).

Using data on representative household surveys across the world, Hallegatte and Rozenberg (2017) provided evidence that the indirect impacts of CC hazards through food prices and labour markets fall disproportionately on the poor. Letta et al. (2018) showed that temperature shocks contribute to increased inequality in Tanzania through their impacts on crop yields and total factor productivity. Other important mechanisms for transmission of CC hazards include their impacts on health and migration (IPCC, 2014c) and conflicts (Eberle et al., 2020), all with special heavy burdens on women in rural areas (Eastin, 2018).

It is also important to point to the fact that the focus of all above assessments is on evaluation of impacts of CC on only income poverty, whereas poverty is multidimensional as defined by the various constituents of the sustainable development agenda 2030 (UN, 2019). We return to this point in the following section examining the consistency and compatibility of climate actions with the Sustainable Development Goals (SDGs).

How pro-poor are climate actions?

The international community has reached consensus on several mitigation and adaptation measures to manage CC and its serious negative consequences for the future of life on earth. Mitigation aims to collectively achieve reduction of emission and concentration of greenhouse gases (GHSs) to levels required for stabilizing global temperatures within safe limits. Adaptation measures on the other hand, are introduced to assist communities at risk and less prepared to cope with the adverse impacts of CC. To what extent are the agreed climate mitigation and adaptation actions address IPCC's assessment that "climate change and climate variability worsen existing poverty and exacerbate inequalities (Olsson et al., 2014)" is the focus of this section.

By adopting the principle of "common but differentiated responsibilities and respective capabilities", the United Nations Framework Convention on Climate Change (UNFCCC) explicitly acknowledges differences between countries and social groups in the responsibility for causing and the capacity to cope with the adverse impacts of CC (UNFCCC, 1998). Implications of CC for P&I are however, addressed differently by the two climate action measures, i.e., adaptation and mitigation.

Protocols and programmes for supporting adaptation to CC are designed to directly target the poor and most vulnerable in providing needed assistance. Although the current emphasis of the international community is on obtaining global agreement on aggressive actions for a more ambitious mitigation goal, it is important to evaluate the performance of applied climate adaptation practices in terms of their impacts on P&I. None of the AERC-CCEDA project studies looked at impacts of climate adaptation programs and actions on P&I, and hence the focus of this section is on climate mitigation actions.

Climate mitigation actions are based on several global and regional agreements and protocols ratified by the international community. Key among those is the UNFCCC, Kyoto Protocol, Copenhagen Accord, Cancún and Paris agreements. Various technological, institutional, and economic policy measures were proposed under these agreements to be collectively introduced by all countries to mitigate CC. All climate mitigation actions are expected to have important implications for the state of P&I in the world. A framework for studying the implications of climate mitigation measures for P&I in SSA was developed by Hassan and Mabugu (2021) – (H&M) under the AERC-CCEDA project. The H&M study provided a critical assessment of the extent of attention P&I have received in the literature on climate mitigation and proposed an analytical framework and empirical methodology for conducting multi-country investigations of the P&I implications of climate mitigation policy measures.

SSA participation in and utilization of climate mitigation agreements

According to the principle of *common but differentiated responsibilities* the mitigation protocols placed the main responsibility for reduction of GHGs emissions and loading on countries of the industrialized world given their historic carbon footprints compared to developing countries. In addition to commitments to achieve set emission reduction targets, developed countries have been required to aid necessary for developing countries not only to adapt to CC adverse impacts but to also participate in mitigation efforts. The two most important mechanisms introduced to support the transition to a low carbon growth path are the climate finance instruments and mitigation technology transfers. The H&M study examined the extent to which SSA participated in and benefited from these climate mitigation instruments.

H&M argued that global climate agreements induced regional and country level mitigation programmes in SSA. Good examples include several collaborative regional initiatives, such as: (a) the efficiency through standards and labelling for West Africa, (b) transboundary pooling of power sources (e.g., cross-border electricity grid), (c) the Congo Basin REDD+ initiative, and (d) the Great Green Wall of the Sahara (Agrawala et al., 2014). Moreover, The European Union (EU) Emissions Trading Scheme (ETS) enabled EU countries to obtain emission credits from countries in SSA through the Clean Development Mechanism (CDM) and Joint Implementation (JI) projects (IPCC, 2014b).

International funding has been the main source of finances for SSA's participation in climate mitigation actions. The H&M study revealed that SSA received US$ 3.7 billion of international climate finance between 2010 and 2012 (11% of total). The largest support to participation of SSA in climate mitigation was from the International Emissions Trading (IET) instruments (US$ 57 billion, representing the total global IET investment in 2018 [ICAP, 2019]). CDM projects ranked second in sources of external funding for climate mitigation in SSA, contributing US$ 17.277 billion. Nevertheless, SSA remains the least among beneficiaries from the global investments in CDM projects at the very low share of 3.2% (Table 1). These were followed by funds from the Great Green Wall Initiative (GGWI)[1], the Clean Technology Fund (CTF), and Reduction of Emissions from Deforestation and Degradation (REDD+). While revenue from carbon taxes has become a major source of climate finance, introduction of these measures in SSA is recent, and only two countries (South Africa and Gabon) are planning such initiatives (World Bank, 2019). Table 1 suggests that SSA countries levels of utilization and shares in total outlays of global and regional climate mitigation mechanisms and financing instruments (i.e., CDM, GEF, GCF, CTF, SCCF, REDD+) remains very low.

Table 4: Size of SSA countries participation in global and regional instruments for climate change mitigation between 2008 and 2019 (depending on availability of data)

Mitigation agreements and mechanisms	2008		2012		2018/19	
	Million US$	% of total	Million US$	% of total	Million US$	% of total
International Emissions Trading (IET)	DNA	DNA	DNA	DNA	57,300	100%
Clean Development Mechanism (CDM)	77	0.3%	9,340	2.6%	17,277	3.2%
The Great Green Wall Initiative (GGWI)	DNA	DNA	DNA	DNA	8,000	100%
Clean Technology Fund (CTF)	0	0%	433	20.1%	524	10.5%
REDD+	4	0%	92.6	15.1%	522	24.3%
Global Environment Fund (GEF) Mitigation	63.5	12.4%	163	12.4%	410	16.6%
Scaling Up Renewable Energy Program (SREP)	0	0%	0	0%	244	54%
Global Climate Fund (GCF) Mitigation	0	0%	0	0%	209.4	11.7%
Strategic Climate Finance (SCCF)	10.4	22.5%	23.8	14.6%	33.5	11.7%

DNA refers to data not available

Source: Adapted from Hassan and Mabugu (2021)

1 The GGWI was launched in 2007 by the African Union to "restore Africa's degraded landscapes and transform millions of lives in one of the world's poorest regions, the Sahel". Twenty (20) partners including the European Union, World Bank, and the GEF support the GGWI. The initiative has received about US$ 8 billion of pledged funding (Puiu, 2019; and Bilski, 2018).

Impacts of climate mitigation actions on P&I

Mitigation is all about protecting future generations against CC risks by controlling over consumption of the current generation at the expense of the welfare of future folks, and hence aspires to ensure *inter-generational equity* (Stern, 2007; Nordhaus, 2008; Gollier, 2012; IPCC, 2014b). Aiming for low carbon growth through mitigation actions will therefore be beneficial to all rich and poor in the future. Mitigation, however, implies some sacrifices in terms of levels of current consumption to forego, the distribution of the burdens and costs of which among present generation may not be in favour of the poor.

The H&M study provided a comprehensive review of the literature on how climate mitigation science and policy has addressed P&I. Key questions about the optimal timing and magnitude of required climate mitigation efforts have been investigated. Most important among those questions was determining the socially optimal rate for discounting the welfare of future generations (Stern, 2007; Nordhaus, 2008; Dasgupta, 2008; Sterner and Persson, 2008, Arrow et al., 2013, Heal and Milner, 2014). The design of mitigation policy and actions have been greatly influenced by this strand of research. Examples include the consensus on urgency of action (*the need to act now*) and the importance of investing in climate mitigation assets (Stern, 2007; World Bank, 2010). The main global climate mitigation protocols have also addressed intra-generational equity, primarily between countries through adoption of the equity principle of "common but differentiated responsibilities and respective capabilities (CBDRRC)". This led to separation of developed from developing countries in the division of responsibility for mitigation (UNFCCC, 1998; Fischer and Morgenstern, 2010).

Nevertheless, the distribution of P&I impacts of climate mitigation actions among present generations within countries remain poorly researched and understood. For instance, studies that evaluated the socioeconomic impacts of CDM projects compared changes in national level aggregate indicators that reflect between countries' variations, not the within countries' distribution of realized benefits (He et al., 2014). Few studies evaluated within-country distributional impacts of climate mitigation programs using actual observational data (i.e., ex-post assessments). Works of Pecastaing et al. (2018) in Peru, Mori-Clement (2019) in Brazil, Du and Takeuchi (2019) in China are examples we could find of this literature. The literature, however, does not show strong evidence in support of the CDM as a pro-poor mitigation instrument, and in some cases was found to even worsen existing P&I (Baker and Newell, 2014).

The literature suggests undesirable P&I implications of the REDD+ and promotion of biofuels mitigation mechanisms. Green land grabbing and displacement of local communities, appropriation of benefits by local elites (Chomba et al., 2016; Bayrak and Marafa, 2016; Corbera et al., 2017; Saeed et al., 2018; Markkanen and Anger-Kraavi, 2019), and hiking of food prices in non-Annex I countries (Hussein et al., 2013; Cororaton et al., 2010) have been blamed for the observed undesirable P&I impacts. On the other hand, studies on the socioeconomic impacts of biofuels in Mozambique, Tanzania, Malawi, and Zambia, indicated favourable P&I impacts (Arndt et al., 2012; Hartley et al., 2017; 2019; Schuenemann et al., 2017). Contradicting results have been obtained by studies on the social impacts of voluntary carbon offsets (VCOs) projects (Antle and Stoorvogel, 2008; Jindal et al., 2012; Estrada and Corbera, 2012).

Majority of the fuel emission taxes' studies indicate pro-poor impacts of these price mitigation measures (Coady et al., 2015; Ohlendorf et al., 2018), while some suggest the opposite. The disagreement has been attributed to variations in the type of fuel and recycling of the tax revenues (Renner et al., 2018 and 2019; Renner, 2018; Markkanen and Anger-Kraavi, 2019; Wang et al., 2019; Dorband et al., 2019).

H&M found very few studies assessing the P&I impacts of climate mitigation policies in SSA. Studies by Saeed et al. (2018) and Jindal et al. (2012) conducted qualitative assessments of the implications of REDD+ interventions, respectively, in Ghana and Mozambique. Two other studies (van Heerden et al., 2005; Devarajan et al., 2011) evaluated the P&I impacts of taxing carbon emissions in South Africa (i.e., before introduction of the tax).

The H&M study appears to reveal indications in the literature of some trade-offs between mitigation and reduction of P&I goals. The issue of how synergetic and interdependent climate mitigation response strategies and the SDGs have been taken up in a new body of literature after adoption of the Paris Agreement and the UN 2030 agenda for sustainable development in 2015 (von Stechow et al., 2015; Dennig et al., 2015; Gomez-Echeverri, 2018, Markhanen and Anger- Kraavi, 2019). Hubacek et al. (2017) showed that pursuing reduction of P&I (goals 1 and 6 of the SDGs) will require more ambitious emission reduction targets. Along the same lines, Jin et al. (2018) established a negative relationship between poverty and mitigation of CO_2 emissions in China. Palomo et al. (2019) arrived at similar conclusions.

Impact pathways framework for studying linkages between climate mitigation actions and P&I

The H&M paper developed an analytical framework that mapped main channels through which climate mitigation measures get transmitted or mediated to P&I impacts. Mediation analysis was proposed to enable identification of the appropriate methods to use to measure and evaluate the merits of alternative mitigation policy measures. H&M adapted the approach of Markkanen and Anger-Kraavi (2019) to characterize the complex dynamic interlinkages between climate mitigation and P&I. Figure 2 presents the H&M impact transmission channels and feedback linkages between climate mitigation actions and P&I. The adapted framework allows for both positive and negative P&I outcomes depending on the context, nature and implementation of the mitigation policy measures to be assessed. Positive outcomes obtain when higher employment and income opportunities are likely with climate mitigation actions. Markkanen and Anger-Kraavi (2019) suggest that creation of forest carbon markets, improved access to electricity, better public sector transport connectivity, retrofitting of existing buildings and development of energy efficient technologies, and locating large-scale renewable energy systems in deprived areas have potential to generate positive impacts. On the other hand, P&I are most likely to worsen when mitigation policies raise costs of essential goods (e.g., food and energy). This is because the share of such goods in the poor's total spending is high.

The H&M study proposed approaches to model and quantify the impacts of climate mitigation on P&I including data sets needed for implementing such empirical investigations.

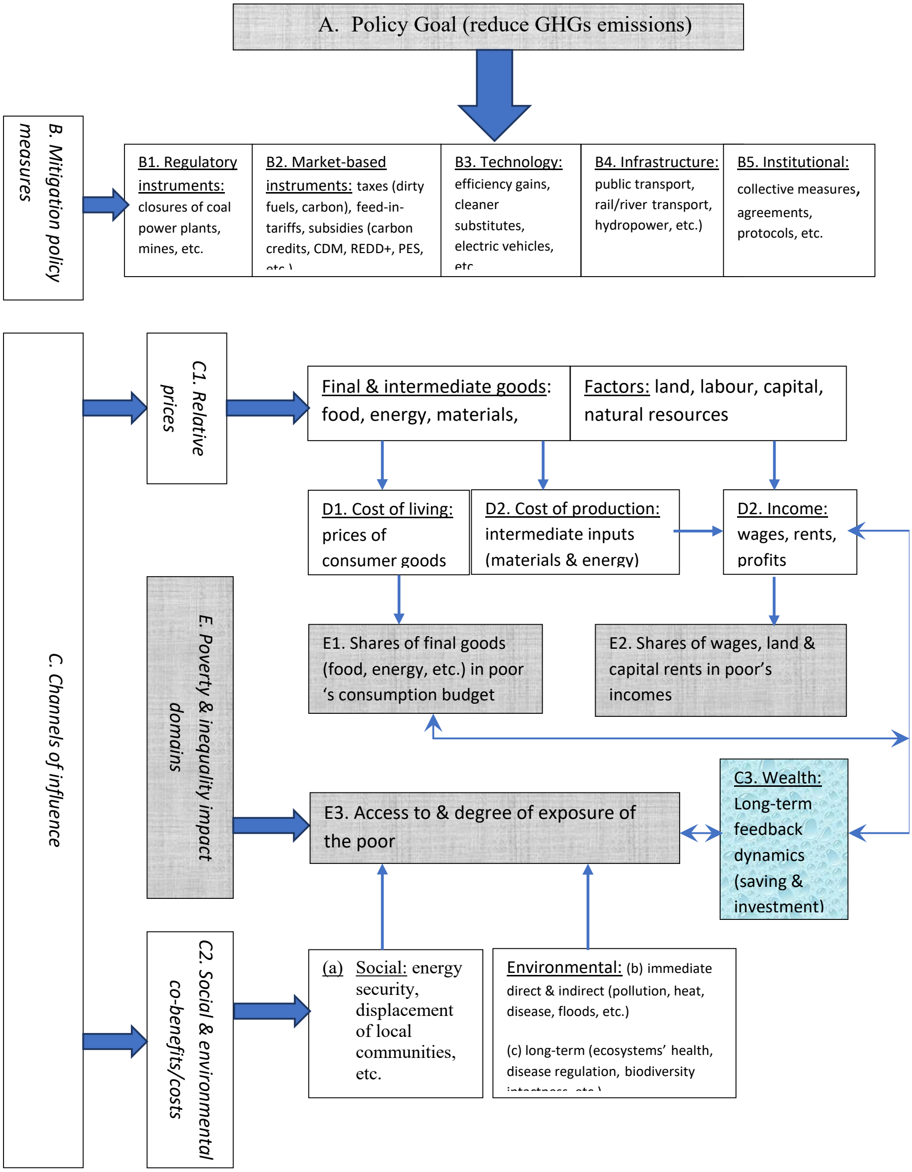
COVID-19, climate change and P&I

As none of the studies commissioned under the AERC's CCEDA project addressed these aspects, our assessment of the links between COVID-19, CC and P&I presented in this section draws on critical reading of available literature of relevance. A recent UNEP and ILRI (2020) report named CC among the top anthropogenic (human-mediated) drivers of the emergence of zoonotic diseases, stating that, "survival, reproduction, abundance and distribution of pathogens, vectors and host animals" are sensitive to CC. Warmer temperatures and wetter conditions appear to be favorable for higher disease incidence, generally with greater illness, by "increasing the vector population size and distribution and by increasing the duration of the season in which infectious vector species are present in the environment" (UNEP and ILRI, 2020). Examples include the mosquito-borne Rift Valley fever, the *chikungunya* and West Nile virus, the insect-transmitted *chagas* disease, sand-fly transmitted leishmaniasis, and other vector-borne and zoonotic diseases (UNEP and ILRI, 2020).

Like global warming, the recent outbreak of COVID-19 pandemic is another powerful message awakening the world to how dangerous crossing natural limits can be for the future of human wellbeing. Both CC and the outbreak of COVID-19 are linked to failure or absence of the institutional setup needed for internalizing consequences of private agents' choices in pursuit of boundless growth in consumption. While CC is the result of GHG emissions overloading the regulating sink services of atmospheric ecosystems, COVID-19 is attributed to disrupting the functional integrity of natural life-support systems (biodiversity) (UNEP and ILRI, 2020). Both grow from a problem of excessive exploitation of local commons to a global commons' problem that requires coordination and collective actions by all stakeholders at local and global levels.

Other differences include the nature and dynamics of impacts. While CC is a slow process of change and its impacts are delayed but long-lasting, pandemics are fast spreading and inflict immediate direct impacts that require quick actions (emergency medical services to save lives and measures to contain spreading, e.g., lockdowns, social distancing, and vaccination). Pandemics also tend to last for shorter durations with high uncertainty about chances of recurrence in the future. Although records indicate that lockdowns and other measures to contain the spread of COVID-19 reduced GHG emissions, the pandemic has major implications for P&I, which we cover in the following subsection.

Figure 4: Impact pathways of climate mitigation to poverty and inequality



Global warming and disease pandemics, however, differ in several ways important for environmental management and development policy in SSA. Most important differences relate to the source of the problem and targets for policy actions. In the case of CC, the problem is excessive emissions from intensive energy use in relatively more formal and organized sectors of economic activity (i.e., integrated in formal economic systems). Needed corrective policy measures and objects to target and influence for a desired change are therefore relatively clear. On the other hand, COVID-19 is linked to humans' interference with the natural habitat of animal species, and typically associated with encroachment and mismanagement of local commons, correction of which requires policy measures to influence change in complex governance regimes (UNEP and ILRI, 2020; Hassan et al., 2019).

Impacts of COVID-19 on P&I

The numbers are telling of the magnitude and scale of the COVID-19 catastrophic impacts, causing the loss of more than 5.5 million lives (WHO, 2022) and all accompanied human suffering, economic costs, and social stress inflicted on people over the past two years. The global economy has been predicted to contract by between 5% to 20% due to COVID-19 (Vos et al., 2020; Sumner et al, 2020; IMF, 2020a). It is estimated that jobs lost remain at an equivalent of 137 million fulltime jobs in the third quarter of 2021 (lower by -4.7% than pre-pandemic employment levels) and huge numbers of firms went out of business since the start of the pandemic (ILO, 2021). SSA's share of job losses was higher than the world average at -5.6% (ILO, 2021).

Major concerns are with the fact that these burdens are falling disproportionately on the poor and disadvantaged in the world eroding gains made towards achieving several of the SDGs (Vos et al., 2020; Sumner et al, 2020; Lakner, 2020; Adams-Prassl et al. 2020). The International Labor Organization (ILO) predicted worsening of relative poverty in the informal sector as the proportion of the working population earning less than half of median wages is expected to increase by 34% (ILO, 2020)[2]. This represents a serious regressive impact of COVID-19 on efforts to reduce P&I when one realizes that over 60% of all workers worldwide and three quarters of developing countries' workers are in informal employment (UN, 2020).

Impacts of COVID-19 tend to reflect existing structural inequalities, not only between the poor and rich, but also between the old and young, those with and those without good access to medical care and internet connections, men, and women, among others. The gender divide is one important source of inequalities in bearing the burden of the pandemic. By virtue of their domestic and professional roles, women are more impacted by the pandemic than men. This is because 70% of the health workforce are women, mostly at the front-line, especially doctors, nurses, cleaners, and providers of similar services at hospitals (Elson and Mama, 2021). Also, women are the ones providing the needed care for ill members of the family and all children staying home during closure of

2 A steep 60% decline in the earnings of informal workers have been estimated in the first month of the pandemic crisis (Rolph van der Hoeven, 2021).

schools and lockdowns. Another suffering sustained by women is the increased domestic violence against them in locked down households as has been reported in all parts of the world (Elson and Mama, 2021).

Not only direct damages of the pandemic itself but also the burdens of measures used to contain its spread are disproportionately borne by the poor and disadvantaged. Like the differential gender impacts mentioned above, lockdowns and social distancing measures for example, are hard to comply with for those employed in informal sectors, such as street venders. The fact that informal sectors' activities are dominated by the poor makes them face the tough choice between safety of health and livelihoods, given that the consequences of both choices could lead to equally devastating outcomes (i.e., ill health and possible death from the pandemic or starvation). The poor also, typically reside in crowded slums and neighborhoods with congested public facilities (e.g., hospitals, schools, shops, outdoors). Majority of the poor also mostly do not own private means of commuting but depend on the generally crowded public means of transport. Clearly all these circumstances make it relatively more difficult for the poor to benefit from social distancing measures.

COVID-19 has greatly exposed the digital divide as the world resorted to isolationist response measures to contain spread of the pandemic. As a result, those who had access to reliable power supply and digital infrastructure were able to cope with lockdowns and social distancing by doing business from home, distance learning, and shopping online. In general, the poor of the world have been severely disadvantaged in this regard as they lack access to internet connection. This has been the case in less developed countries, particularly SSA[3], where many millions have no access to regular electricity supply and internet connections, especially the poor in rural areas and all those engaged in informal sectors' activities, employees, and small enterprises alike (Blimpo and Cosgrove-Davies, 2019; IMF, 2020b). Through the digital divide the pandemic has deepened existing structural inequalities to the disadvantage of the education of children of the rural poor and participants in informal economic activities, especially in the developing world.

Isolationist measures also impacted trade flows and mobility of goods and people across countries as borders had to be at least partially closed. Less developed countries highly dependent on international trade were the most affected as well as multilateral cooperation in general (WB, 2020; CDP, 2021). Vulnerability of SSA to quarantines and other restrictions on movement of goods is obvious since more than half of Africa's exports and imports are to and from countries highly impacted by Covid-19. Restricting exports of medical supplies by many countries have also heavily impacted SSA's capacity to respond to Covid-19 because all countries in SSA are net importers of medicinal and pharmaceutical products (94%) (UNECA, 2020a).

3 Less than half (43%) of the population (25% in rural areas) have access to electricity in SSA compared to a global access rate of 87% (Blimpo and Cosgrove-Davies, 2019).

Measures taken to control the spread of the pandemic are bound to trigger global economic slowdown, the burdens of which will not be equally shared. Low income and highly indebted countries with less fiscal space to support stimulus packages, poor public health resources, and uneasy access to vaccines will bear the brunt of these economic damages. Predictions indicate that COVID-19 can lead to economic costs in Africa estimated at $500 billion. According to the WB (2020), economic growth in SSA's GDP is predicted to drop from 2.4% in 2019 to between -2.1 to -5.1 percent in 2020 leading to the first recession in the region in 25 years. Circumstances in SSA in terms of most of the structural disadvantages outlined above (structural inequities, gender, and digital divide, etc.) make it one of the most vulnerable regions to regressive P&I impacts of damages inflicted by COVID-19. More than 55% of the population in SSA are living in slums with no or congested access to basic services and amenities (e.g., clean water and sanitation, medical care[4], social protection, public means of transport, etc. [WB, 2020]). Enforcing lockdowns and social distancing is in most cases infeasible on participants in informal sector activities (street vendors and food servers, waste recyclers, construction, transport and domestic workers), which employs 85.8% of the population in SSA (ILO, 2018), is seriously disadvantaged in terms of digital infrastructure as it is estimated that, in 2017, only 24% of the population in SSA use internet compared to 64% in the rest of the world (IMF, 2020b). Limited electricity supply, poor and high-cost information, and communication technology (ICT) infrastructure, and digital illiteracy, are major constraints on the ability to switch to telework for doing business, schooling, etc. in SSA (Blimpo MP, Cosgrove-Davies; Bakibinga-Gaswaga et al., 2020; IMF, 2020b).

SSA however, has a population age composition advantage as the median age is 20 years with a low ratio of 5.5% of vulnerable old aged (>60 years) in the population, compared to 25.6% in Europe (UN, 2020), which suggests relatively lower risk of developing the severe symptoms of Covid-19. Similarly, there is relatively more room for social distancing in SSA where the population density (51 people/km^2) is well under European and South Asian averages (respectively, 128 people/km^2 and 380 people/km^2).

COVID-19 and the trade-offs between livelihoods and nature conservation in SSA

It is estimated that about 60% of all human infectious diseases such as COVID-19 are zoonotic, i.e., have an animal origin (UNEP and ILRI, 2020). Zoonosis represents a major source of risk to human health in SSA as cohabitation and interactions between humans and animals, both in the wild and domesticated, are quite common and extensive. Hunting from the wild for bushmeat for example, is widespread, especially around local commons. FAO et al. (2019) estimated that 57.7% of the population in SSA in 2018 were food insecure and hence was highly reliant on wildlife hunting. Statistics indicate that game hunting provides 30-80% of the protein intake in rural Central Africa (FAO, 2015), and bushmeat provides about 80-98% of animal protein to rural communities in

4 Africa has 1.8 hospital beds per 1,000 people compared to 5.98 in France (UNECA, 2020b).

Cameroon (Muchaal and Ngandjui, 1999). Records also show that bushmeat is regularly consumed by 30-60% of rural households in South Africa (Martin and Shackleton, 2019), 80% in Kenya, and 46% in Botswana at average amounts of more than 14 kg per month (Barnett, 1998).

Exploitation of the wild for bushmeat has been identified as the most serious threat to wildlife in SSA's protected areas. In West and Central Africa, a total of 177 species (76% mammals and 14% bird) are hunted for bushmeat (Taylor et al., 2015). Hunting for bushmeat is practiced in 96% of protected areas in Kenya (Okello and Kiringe, 2010), and more than one million wildlife species are killed for bushmeat every year in Central Africa (Wilkie et al., 1999). Endangered species are also targeted for bushmeat in SSA, and it is estimated that 7% of the chimpanzee population is hunted annually in the Republic of Congo (Twining-Ward and Chapman, 2020). Records also show that 4.5 million tons of bushmeat are confiscated annually in the Congo Basin (Nasi et al., 2011). Bushmeat is not a source of protein only but also considered a crucial safety net for many households in SSA, especially for the extremely poor and/or for lack of alternative income-generating activities[5]. In rural Equatorial Guinea 60% of poor households were found to sell 89% of their bushmeat for cash income (Kumpel et al., 2010), and bushmeat contributes €142.7 million per year, about the same as the mining sector, to Cameroon's gross domestic product (Lescuyer and Nasi, 2016). In rural Gabon, bushmeat contributes up to 72% of households' income (Starkey, 2004). Table 5 below shows examples of economic benefits from selling bushmeat in some SSA countries.

Table 5. Amounts of hunted bushmeat per year in some SSA countries

Country	Average Amount/ Per Year	Source
Côte d'Ivoire	120,000 tons	Caspary, 1999
Ghana	385,000 tons	Ntiamoa-Baidu, 1998
Democratic Republic of the Congo	1,665,972.491tons	Nasi et al., 2011
Cameroon	87,800 tons	Lescuyer and Nasi, 2016

Trade restrictions caused by lockdowns are likely to contribute to increased illegal game hunting as similar experiences in Zambia and Malawi suggest (Cochrane, 2020). As wildlife-based tourism in Africa provides about US$71 billion annually (Biggs et al., 2020), it is expected that as this business is adversely affected by COVID-19, this will lead to increases in game hunting (Twining-Ward and Chapman, 2020).

5 Bushmeat contributes to 28% of total subsistence and cash income for rural communities in developing countries (Angelson et al., 2014) and trade in bushmeat is particularly attractive for those located in areas that are far away from market centers (Wilkie et al., 2016).

COVID-19 lockdowns restrict labor mobility and hence cause loss of employment and negatively impacting livelihoods in rural areas. This is especially significant for pastoral systems, where labor sharing arrangements in pasture surveillance and livestock guarding is fundamental for pastoral production.

Conclusions and policy implications for equitable green recovery in SSA

There is compelling evidence in the literature that both CC and pandemics exacerbate existing structural inequalities and adversely impact the poor and marginalized more than other relatively well-to-do social groups. It is therefore obvious that combating CC and COVID-19 will be necessary for realizing reduction in P&I. It is also clear that several of the measures introduced and tested for mitigation of the damaging impacts of CC and containing the spread of COVID-19 have undesirable consequences on the state of P&I as well as other related SDGs. This implies that synergy and complementarity between the SDGs and actions aiming to mitigate CC and control pandemics must be ensured to avoid the worst of global warming and COVID-19. In this section, a comprehensive set of principles are recommended to guide the design of a strategy and policies for healthy, green, and inclusive future for SSA.

1. Since the SDGs are multidimensional, *all global and national climate mitigation and COVID-19 containment policy measures and actions need to be evaluated for consistency with the broader scope of SDGs*, particularly developmental objectives, and security of access to basic socio-economic services (e.g., poverty and hunger eradication; reduced inequity; food, water, and energy security; universal education and health services; leaving no one behind, among others).
2. At the top of the agenda is *removing existing structural inequalities* by increasing the resilience of vulnerable ecosystems and social groups to the hazards of CC and pandemics. Priority in this regard should be accorded to bridging the country, gender, and digital divides with special support programs. Assistance to enhance the capacity to adapt to and mitigate CC and contain and prevent onslaught of pandemics must target low-income countries, women, and other marginalized groups (e.g., informal sectors, minority ethnic groups, remote regions, etc.). The following represent priority areas for urgent attention and assistance in this regard:
3. *Subsidizing favourable livelihoods' options for the poor and marginalized:* This includes policy measures that would improve equity outcomes of climate mitigating measures, such as recycling revenue from carbon taxes to benefit low-income groups, and relaxing other barriers of access to essential amenities (food, energy, water, health, education). Various targeted subsidy and safety net schemes, micro-credit, tax reliefs and extended payment schedules, grants and interest-free loans are candidate measures for supporting desirable distributional outcomes. Guaranteed provision of vaccines, diagnostics, tests, and treatments at subsidized or free of charge to the most vulnerable, particularly front-line, and informal sectors' workers will be necessary at times of pandemic outbreaks. Removal of tariffs on essential

Covid-19 imports (protective garments, disinfectants and sterilization products, medical consumables, testing kits, etc.), which are currently high in Africa reaching up to 40% for some of these items (UNECA, 2020a), will lower costs for all.

Sufficient investments in universal provision and security of access to medical attention, decent housing, education, and energy; mobility and gainful employment for urban and rural labour, and integration of informal activities in organized modern spheres of the economy, are critical strategies for ensuring longer term reduction of structural P&I.

4. *Addressing the digital divide:* The event of COVID-19 triggered major changes in the way digital technology can be used that reshaped lifestyles and business models. The world has quickly responded to lockdowns by switching to remote working, schooling, shopping, and delivery of many services. As access to on-line resources is not universal, these changes exposed existing structural inequalities, negatively affecting the ability to run business and acquire education for those without access to digital infrastructure, who are predominantly poor and marginalized, especially in remote rural areas.

   It is highly likely that the switch to remote working and on-line learning will continue to grow after COVID-19. Scaling up investment in digital infrastructure, which requires access to electricity, mobile and internet coverage will be necessary for addressing the digital divide and reduction of P&I. SSA has an opportunity to learn from earlier experiences in Kenya, Rwanda and Côte d'Ivoire where digital platforms to conduct business have been adopted (IMF, 2020b).

   Digital access is also crucial for higher resilience to pandemics among less equipped and remote communities as online resources facilitate timely communication of early warnings and recommended early responses. Adequate digital infrastructure such as use of satellite and drones can play a critical role in wildlife monitoring, which should assist with protection of the local commons against poaching and illegal trade in wildlife, with positive implications for conservation of biodiversity and reduction of risks of emergence of pandemics in the future.

5. *Eliminating the gender divide:* The literature suggests that CC and COVID-19 reinforce existing gender inequities. Women were found to be more vulnerable to and bear relatively bigger shares of the burden of damages caused by the pandemic and CC. Huge inequities in ownership of assets, especially land[6], increasing economic responsibilities and domestic burdens during lockdowns and as a result of male out-migration after disasters, discriminatory social norms and intra-household division of labour, and limited mobility and opportunities for employment in non-sextually stratified jobs, constitute the main reasons for the structural inequities and sources of relatively higher vulnerability among women (Eastin, 2018; Elson and Mama, 2021).

6 In Africa, women are responsible for between 50 and 80% of agricultural production but hold title to less than a 20% all agricultural land (FAO, 2016).

To ensure progress towards reducing P&I and achieving SDG 5 on gender, policy measures to enhance resilience to CC and pandemics must accordingly pay special attention to empowerment of women and removal of the said sources of the gender divide.

6. *Supporting low income and vulnerable economies:* Both CC and pandemics are problems of managing global commons, which require international cooperation for collective actions to combat their adverse impacts. There is need for multilateralism that will facilitate mobilization of the financial and technological assistance needed to support capacities of relatively poorer and resource constrained countries to adequately respond to CC and the COVID-19 pandemic risks. Assistance from rich and technologically advanced countries, international organizations, and the corporate world will be critical for the success of global actions to mitigate the damages of CC and the pandemic and simultaneously achieve the desired reduction in P&I. Proposals for successful multilateralism in this respect include:
7. Provision of adequate multilateral finance instruments to assist developing countries adapt to and mitigate CC and contain pandemics like COVID-19
8. Debt relief arrangements such as cancellation of sovereign debts owed by vulnerable economies
9. Special funds to enable public health sectors in poorer countries with limited fiscal space and least capacity to save lives to provide access to vaccines, treatment, and diagnostics
10. Global cooperation in digital technology transfer, sharing of data and knowledge, and access to medical intellectual property (e.g., emergency exemption from rights' protections on Covid-19 medical supplies, and sharing of novel patents, design schematics, and industrial techniques to support domestic production, particularly for pharmaceuticals and delivery of vaccine doses timely when needed - WTO (2001).
11. Adoption of the *One Health* approach (FAO-OIE-WHO Tripartite Alliance) that recognizes the complex interconnections and integrates the goals of protecting the health of human and animal communities and the environment.
12. *Importance of the role of the government*. Reducing GHGs emissions, lowering risks of emergence of pandemics, and eradication of absolute poverty and social inequities are not the goals of typical private economic agents' decision making. These are public goods that markets cannot directly deliver and need interventions from a public agency, such as the government and/or global protocols for their provision. Therefore, public policy and investment will be required to direct markets towards green, inclusive, and sustainable futures. While governments must assume the lead role, innovative mechanisms will be needed for mobilizing collaboration and commitment from the private sector to the social contract.
13. *Implementing African initiatives for inclusive green recovery and sustainable development:* Several important initiatives have been endorsed by African states to guide continental efforts towards equitable, safe, and green future. Key among

those is the African Green Stimulus Programme (AGSP) of the African Ministerial Conference on the Environment (AMCEN), which aims to enable achievement of Africa's Agenda 2063, the UNFCCC, and its Paris Agreement agenda, the 2030 SDGs, and safe recovery from COVID-19. The AGSP is an African-led initiative "intended to bring about a unifying Continental response by enhancing and forging partnerships between Intergovernmental Organisations, African countries, the Private Sector and Non-governmental Organisations in the support of a comprehensive Green Recovery programme for Africa" (AMCEN, 2021).

One of the main aims of the AGSP is to combat illegal and unregulated wildlife exploitation and trade to reduce risks of potential emergence of zoonotic disease pandemics like COVID-19 in the future. It is predicted that "pandemics are likely to happen more frequently, spread more rapidly, have greater economic impact and kill more people" (Settele et al., 2021). It is accordingly necessary to strengthen enforcement of regulations for protection of human and nature's health such as banning wildlife trade and hunting. In response to the pandemic, few SSA countries took immediate actions to reduce wildlife hunting and trade, with Gabon, Zambia and Botswana taking the lead (RFI, 2020; Biggs et al., 2020).

References

Adams-Prassl, Abi; Teodora Boneva, Marta Golin, and Christopher Rauh. 2020. "Inequality in the Impact of the Coronavirus Shock: Evidence from Real Time Surveys". *Journal of Public Economics* (189). https://doi.org/10.1016/j.jpubeco.2020.104245.

Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx, eds., *Climate change 2014: Mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Agrawala S., S. Klasen, R. Acosta Moreno, L. Barreto, T. Cottier, D. Guan, E. E. Gutierrez-Espeleta, A.E. Gámez Vázquez, L. Jiang, Y. G. Kim, J. Lewis, M. Messouli, M. Rauscher, N. Uddin and A. Venables, 2014. "Regional development and cooperation. In: Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A.

Angelsen, A., Jagger, P., Babgumira, R., Belcher, B., Hogarth, N., Bauch, S., Borner, J., Smith-Hall, C., Wunder, S. 2014. Environmental Income and Rural Livelihoods: A Global-Comparative Analysis, *World Development, Volume 64, Supplement 1*, Pages S12–S28

Andrianarimanana, D. 2015. The role of inter-household transfers in coping with post-disaster losses in Madagascar, in Clarke, D., deJanvry, A., Sadoulet, E., and Skoufias, E. (eds.), Disaster Risk Financing and Insurance: Issues and results, Workshop Proceedings, held at the Ferdi on June 4 and 5, 2015, FERDI, WB, GFDRR, UKaid.

AMCEN (African Ministerial Conference on the Environment). 2021. African Green Stimulus Programme, UNEP, Nairobi.

Antle, J. and Stoorvogel, J. 2008. “Agricultural carbon sequestration, poverty, and sustainability”. *Environment and Development Economics*, 13: 327–352.

Arrow, K., Cooper, M., Gollier, C., Groom, B., Heal, B., Newell, R., Nordhaus, W., Pindych, R., Pizer, W., Ortney, P., Sterner, T., Tol, R.S.J., and Weitzman, M.. 2013. “Environmental economics: Determining benefits and costs for future generations”. *Science*, 341(6144): 349–350.

Arndt, C., Pauw, K. and Thurlow, J. 2012. “Biofuels and economic development: A computable general equilibrium analysis for Tanzania”. *Energy Economics*, 34: 1922–30.

Bakibinga-Gaswaga, E., Bakibinga, S., Bakibinga, D., and Bakibinga, P. 2020. “Digital technologies in the COVID-19 responses in sub- Saharan Africa: policies, problems and promises”, *Pan Africa Medical Journal*. 2020;35(2):38. DOI: 10.11604/pamj.2020.35.2.23456.

Baker and Newell. 2014. “The political economy of energy transitions: The case of South Africa”. *New Political Economy*,19 (6), 791–818.

Bayrak, M. and Marafa, L. 2016. “Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities”. *Sustainability*, 8 (7): 1–22.

Beegle, Kathleen, and Christiaensen, Luc (eds.). 2019. Accelerating Poverty Reduction in Africa, World Bank, Washington, DC.

Biggs, D., Braczkowski. A., De Vos, A., and Clements, H. 2020. COVID-19, Africa’s conservation and trophy hunting dilemma, *The Conversation, June 2020*.

Bilski, A. 2018. ‘”Africa’s Great Green Wall Initiative: A work in progress’’. *Landscape News,* 3 August 2018. Available at: https://news.globallandscapesforum.org/28687/africas-great-green-wall-a-work-in-progress/.

Blimpo MP, Cosgrove-Davies M. (2019). Electricity Access in Sub-Saharan Africa Uptake, Reliability, and Complementary Factors for Economic Impact. In; *Africa Development Forum series.* World Bank: Washington DC, 2019.

Caspary, H. 1999. Wildlife utilization in Côte d’Ivoire and West Africa - potentials and constraints for development cooperation, TÖB publication no.: TÖB F-V/10e, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Germany.

CDP (Committee for Development Policy). 2021. Development policy and multilateralism after COVID-19, CDP, DESA, UN, New York.

Chomba, S., Kariuki, J., Lund, J. and Sinclair, F. 2016. “Roots of inequity: How the implementation of REDD+ reinforces past injustices”. *Land Use Policy*, (50): 2020–2013.

Coady, D., Flamini, V. and Sears, L. 2015. “The unequal benefits of fuel subsidies revisited: Evidence for developing countries”. In; B. Clements, R. de Mooij, S. Gupta and M. Keen, eds., *Inequality and fiscal policy.* Washington, DC: International Monetary Fund.

Cochrane, J. 2020. COVID-19 reveals costly blind spots in efforts to combat wildlife crime, *Global Initiative Against Transnational Organized Crime*, June 3, 2020.

Cororaton, C., Timilsina, G. and Mevel, S. 2010. Impacts of large-scale expansion of biofuels on global poverty and income distribution. Proceedings Issues, 2010: Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security (June 2010) No. 91279.

Corbera, E., Hunsberger, C. and Vaddhanaphuti, C. 2017. "Climate change policies, land grabbing and conflict: Perspectives from Southeast Asia". *Canadian Journal of Development Studies,* Vol. 38, No. 3: 297–304.

Dasgupta, P. 2008. "Discounting climate change". *Journal of Risk and Uncertainty,* 37(2): 141–69.

Dennig, F., Budolfson, M.B., Fleurbaey, M., Siebert, A. and Socolow, R. 2015. "Inequality, climate impacts on the future poor, and carbon prices". Proceedings of the National Academy of Sciences (PNAS) 112: 15827–15832.

Devarajan, S., Go, D.S., Robinson, S. and Thierfelder, K. 2011. "Tax policy to reduce carbon emissions in a distorted economy: Illustrations from a South Africa CGE model". *The B.E. Journal of Economic Analysis and Policy,* 11(1): 1682–1935.

Diffenbaugh, M. and Burke, M. 2019. "Global warming has increased global economic inequity". Proceedings of the National Academy of Sciences (PNAS) (116): 9808–9813.

Dorband, I., Jakob, M., Kalkuhl, M. and Steckel, J. 2019. "Poverty and distributional effects of carbon pricing in low- and middle- income countries: A global comparative analysis". *World Development,* 115: 246–257.

Du, Yimeng and Takeuchi, K. 2019. "Can climate mitigation help the poor? Measuring impacts of the CDM in rural China". *Journal of Environmental Economics and Management*, 95: 178–197.

Eberle, U., Rohner, D., and Thoenig, M. 2020. Heat and Hate: Climate Security and Farmer- Herder Conflicts in Africa. CEPR Discussion Paper No. 15542. Centre for Economic Policy Research, London.

Elson, D., and Mama, A. 2021. COVID-19 and gender inequality, in CDP (Committee for Development Policy). 2021. Development policy and multilateralism after COVID-19, CDP, DESA, UN, New York.

Eastin, J. 2018. "Climate change and gender equality in developing states". *World Development* 107 (2018) 289–305.

Estrada, M., and E. Corbera. 2012. "The potential of carbon offsetting projects in the forestry sector for poverty reduction in developing countries: The application of ecology in development solutions". In; Carter Ingram, J., F. DeClerck and C. Rumbaitis del Rio, eds., *Integrating Ecology and Poverty Reduction*. New York: Springer.

FAO (Food and Agriculture Organization). 2015. Illegal hunting and the bush-meat trade in Savanna Africa: Drivers, impacts, and solutions to address the problem, FAO, Botswana.

FAO (Food and Agriculture Organization). 2016. Gender and land rights database. http://www.fao.org/gender-landrights-database/data-map/statistics/en/?sta_id=982.

FAO (Food and Agriculture Organization). 2018. Ending Extreme Poverty in Rural Areas: Sustaining livelihoods to leave no one behind, FAO, Rome.

FAO (Food and Agriculture Organization), IFAD, UNICEF, WFP and WHO. 2019. The State of Food Security and Nutrition in the World 2019.

Fisker, P. and Tarp, F. 2021. Poverty and Exposure to Climate Change in sub-Saharan Africa, AERC Working Paper Series: CC-004, African Economic Research Consortium, Nairobi.

Gollier, C. 2012. *Pricing the Planet's Future: The Economics of Discounting in an Uncertain World*. Princeton: Princeton Univ Press.

Gomez-Echeverri, L. 2018. "Climate and development: Enhancing impact through stronger linkages in the implementation of the Paris Agreement and the Sustainable Development Goals (SDGs)". Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376, 20160444.

Hallegatte, S. and Rozenberg, J. 2017. "Climate change through a poverty lens". *Nature Climate Change,* 7: 250–256.

Hallegatte, S., A. Vogt-Schilb, J. Rozenberg, M. Bangalore and C. Beaudet. 2020. "From poverty to disaster and back: A review of the literature". *EconDisCliCha*, 4: 223–47. https://doi. org/10.1007/s41885-020-00060-5.

Hartley, F., van Seventer, D., Tostao, E. and Arndt, C. 2019. "Economic impact of developing a biofuel industry in Mozambique". *Development Southern Africa*, Vol. 36, Issue 2: 233–249. “”

Hassan, R., Mungatana, E., and Akpalu, W. 2019. "Strategies for managing common pool natural resources in Sub-Saharan Africa: A Review of Past experience and future challenges", *Review of Environmental Economics and Policy*, 13 (2): 207–226.

Hassan, R. and Mabugu, R. 2021. Implications of Climate Mitigation Measures for Poverty and Inequality in Sub-Saharan Africa: Framework for Multiple Country Research Study, AERC Working Paper Series: CC-007, African Economic Research Consortium, Nairobi.

He, J., Huang, Y. and Tarp, F. 2014. "Has the Clean Development Mechanism assisted sustainable development?" *Natural Resources Forum*, 38(4): 248–260.

Heal, G. and Millner, A. 2014. "Agreeing to disagree on climate policy". Proceedings of the National Academy of Sciences (PNAS), Vol. 111., No. 10: 3695–3698.

Herrera, C., Ruben, R., and Dijkstra G. 2018. "Climate variability and vulnerability to poverty in Nicaragua", *Journal of Environmental Economics and Policy*, DOI: 10.1080/21606544.2018.1433070.

Hubacek, K., Baiocchi, G., Feng, K. and Patwardhan, A. 2017. "Poverty eradication in a carbon constrained world". *Nature Communications*, 8: 912, doi: 10.1038/s41467-017-00919-4.

Hussein, Z., Hertel, T. and Golub, A. 2013. "Climate change mitigation policies and poverty in developing countries". *Environmental Research Letters*, 8 035009 (10pp) doi:10.1088/1748-9326/8/3/035009.

ICAP (International Carbon Action Partnership) . 2019. Emissions trading worldwide: Status report 2019, ICAP, Berlin.

ILO (International Labour Organization). 2018. Women and men in the informal economy: A statistical picture (Third edition) , ILO. Geneva.

ILO (International Labour Organization). 2021. ILO Monitor: COVID-19 and the world of work. Eighth edition. Updated estimates and analysis (October 2021) 29 April.

IMF (International Monetary Fund). 2020a. World Economic Outlook, October 2020: *A Long and Difficult Ascent*. Washington, DC: International Monetary Fund.

IMF (International Monetary Fund). 2020b. *Regional Economic Outlook: Sub Saharan Africa.* Washington, DC.

IPCC - Intergovernmental Panel on Climate Change. 2014a. Climate change 2014: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Cambridge: Cambridge University Press.

IPCC - Intergovernmental Panel on Climate Change. 2014b. Climate change 2014: Mitigation of climate change. Working Group III contribution to the Fifth Assessment Report, IPCC, Geneva.

IPCC - Intergovernmental Panel on Climate Change - 2014c. Climate change 2014: Impacts, adaptation, and vulnerability. Working Group II contribution to the Fifth Assessment Report, IPCC. Geneva.

IPCC - Intergovernmental Panel on Climate Change. 2014d. Climate change 2014: Synthesis report. Fifth Assessment Report of IPCC. Geneva.

Jin, G., Fu, R., Li, Z., Wu, F., and Zhang, F. 2018. "CO2 emissions and poverty alleviation in China: An empirical study based on municipal panel data". *Journal of Cleaner Production,* 202: 883–891.

Jindal, R., Kerr, J. and Carter, S. 2012. "Reducing poverty through carbon forestry? Impacts of the N'hambita community carbon project in Mozambique". *World Development,* 40(10): 2123–2135.

Kumpel, N., Millner-Gulland, Cowlishaw, G., and Rowcliffe, J. 2010. Incentives for Hunting: The Role of Bushmeat in the Household Economy in Rural Equatorial Guinea, *Human Ecology, volume 38, pages 251–264.*

Lakner, Christoph, Nishant Yonzan, Daniel Gerszon Mahler, R. Andres Castaneda Aguilar, Haoyu Wu, and Melina Fleury. 2020. "Updated Estimates of the Impact of COVID-19 on Global Poverty: The Effect of New Data". *Data Blog*, October 7, 2020.

Lee, Hoesung (2019). Climate change and sustainable development are inseparable, Keynote speech by IPCC Chair during the opening of the High-Level Segment of ECOSOC, at UN General Assembly, New York.

Lescuter, G., and Nasi, R. 2016. "Financial and economic values of bushmeat in rural and urban livelihoods in Cameroon: Inputs to the development of public policy", *International Forestry Review*, *Volume* 18 (S1): 93–107.

Letta, M., Montalbano, P., and Tol, R. 2018. Temperature shocks, short-term growth, and poverty thresholds: Evidence from rural Tanzania, *World Development* 112 (2018) 13–32.

Barnett, R. (1998). Food for Thought: The Utilisation of Wild Meat in Eastern and Southern Africa. Traffic East/Southern Africa. Nairobi.

Martins, V., and Shackleton, C. 2019. "Bushmeat use is widespread but under-researched in rural communities of South Africa", *Global Ecology and Conservation, Volume 17*; doi.org/10.1016/j.gecco.2019.e00583.

Mazzucato, M. 2021. Re-empowering governments for green, equitable and resilient development, in CDP (Committee for Development Policy). 2021. *Development Policy and Multilateralism after COVID-19*, CDP, DESA, UN, New York.

Markkanen, S. and Anger-Kraavi, A. 2019. "Social impacts of climate change mitigation policies and their implications for inequality". *Climate Policy*, 2019, Vol. 19, No. 7, 827–844.

Michaelowa A. and K. Michaelowa. 2011. "Climate business for poverty reduction? The role of the World Bank". *The Review of International Organizations*, 6: 259–286.

Mori-Clement, Y. 2019. "Impacts of CDM projects on sustainable development: Improving living standards across Brazilian municipalities?" *World Development,* 113: 222–236.

Muchaal, P., and Ngandjui, G. 1999. Impact of Village Hunting on Wildlife Populations in the Western Dja Reserve, Cameroon, *Conservation Biology, Volume 13, Issue 2.*

Nasi, R., Taber, A., and Van Vliet, N. 2011. "Empty forests, empty stomachs? Bushmeat and livelihoods in the Congo and Amazon Basins", *International Forestry Review*, Volume 13, Number 3, September 2011, pp. 355–368(14).

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J., Urquhart, P., (2014). Africa, In: Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, Ntiamoa-Baidu, Y., 1998. "Sustainable harvesting, production, and use of bushmeat". Accra: *Wildlife Department, Ghana*.

K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx, eds., *Climate change 2014: Mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Nordhaus, W.D. 2008. *A Question of Balance*. New Haven, CT. Yale University Press.

Okello, M., and Kiringe, J. 2010. "Threats to Biodiversity and their Implications in Protected and Adjacent Dispersal Areas of Kenya", *Journal of Sustainable Tourism, Volume 12, Issue 1: doi.org/10.1080/09669580408667224.*

Ohlendorf, N., Jakob, M., Minx, J.C., Schröder, C. and Steckel, J.C. 2018. Distributional impacts of climate mitigation policies: A meta-analysis WCERE Working Paper. Gothenburg: World Conference on Environmental and Resource Economics (WCERE).

Olsson, L., M. Opondo, P. Tschakert, A. Agrawal, S.H. Eriksen, S. Ma, L.N. Perch and S.A. Zakieldeen. 2014. "Livelihoods and poverty". In Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White, eds., *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Palomo, I., Dujardin, Y., Midler, E., Robin, M., Sanz, M. and Pascual, U. 2019. "Modelling tradeoffs across carbon sequestration, biodiversity conservation, and equity in the distribution of global REDD+ funds". *PANAS*, 1–6.

Pécastaing, N., Dávalos, J. and Inga, A. 2018. "The effect of Peru's CDM investments on households' welfare: An econometric approach". *Energy Policy*, 123: 198-207.

Puiu, T. 2019. ''More than 20 African countries are planting a 8,000-km-Long Greet Green Wall''. ZME Science, 25 April 2019. Available at: https://www.zmescience.com/ecology/climate/great-green-wall-04232/.

Renner, S. 2018. "Poverty and distributional effects of a carbon tax in Mexico". *Energy Policy,* (112): 98–110.

Renner, S., Lay, J. and Schleicher, M. 2019. "The effects of energy price changes: Heterogeneous welfare impacts and energy poverty in Indonesia". *Environment and Development Economics,* (24): 180–200.

Renner, S., Lay, J. and Greve, H. 2018. "Household welfare and CO2 emission impacts of energy and carbon taxes in Mexico". *Energy Economics*, (72): 222–235.

RFI (Radio France International). 2020. Gabon bans eating of pangolin and bats amid pandemic, RFI Life News, 03/04/2020.

Rolph van der Hoeven. 2021. Multilateralism, employment, and inequality in the context of COVID-19, in CDP (Committee for Development Policy). 2021. Development policy and multilateralism after COVID-19, CDP, DESA, UN, New York.

Saeed, A., McDermott, C. and Boyd, E. 2018. "Examining equity in Ghana's national REDD+ process". *Forest Policy and Economics*, (90): 48–58.

Settele, J., Díaz, S., Brondizio, E., and Daszak, P. 2020. COVID-19 Stimulus Measures Must Save Lives, Protect Livelihoods, and Safeguard Nature to Reduce the Risk of Future Pandemics, Expert Guest Article IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), Bonn.

Schuenemann, F., Thurlow, J. and Zeller, M. 2017. "Leveling the field for biofuels: Comparing the economic and environmental impacts of biofuel and other export crops in Malawi". *Agricultural Economics,* 48: 301-15. doi:"https://doi.org/10.1111/agec.12335"10.1111/agec.12335.

Starkey, M. P. 2004. Commerce and Subsistence : the Hunting, Sale and Consumption of Bushmeat in Gabon. Unpublished PhD Thesis, University of Cambridge.

Stern, N. 2007. *The Economics of Climate Change: The Stern review.* Cambridge: Cambridge University Press.

Sterner, T. and Persson, U. 2008. "An even Sterner review: Introducing relative prices in the discounting debate". *Review of Environmental Economics and Policy,* 2(1): 61–76.

Sumner, A., Hoy, C., and Ortiz-Juarez, E. 2020. Estimates of the impact of COVID-19 on global poverty, WIDER Working Paper 2020/43.

Taylor, G., Scharlemann, J., Rowcliffe, M., Kumpel, N., Harfoot, M., Melisch, R., Millner-Gulland, E., Bhagwat, S., Abernethy, K., Ajonina, A., Albrechtsen, L., Allebone-Webb, S., Brown, E., Brugiere, D., Clark, C., Colell, M., Cowlishaw, G., .. Coad, L. 2015. Synthesizing bushmeat research effort in West and Central Africa: A new regional database, *Biological Conservation*, *Volume* 181: 199–205.

Twining-Ward, C., and Chapman, C. 2020. It's time to implement solutions that make the bushmeat trade unnecessary (commentary), Mongabay, USA.

UNECA (United Nations Economic Commission for Africa). 2020a. Trade Policies for Africa to tackle Covid-19, Unpublished briefing paper, African Trade Policy Centre, ECA, Addis Ababa.

UNECA (2020b). COVID-19: Lockdown Exit Strategies for Africa UN (United Nations). 2019. Sustainable Development Goals. Available online at https://sustainabledevelopment.un.org/sdgs.

UN (United Nations). 2020. World Economic Situation and Prospects 2020, New York, United Nations.

UNEP (United Nations Environment Programme) and ILRI (International Livestock Research Institute). 2020. Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission. UNEP, Nairobi, Kenya.

UNFCCC - United Nations Framework Convention on Climate Change. 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. UNFCCC, Bonn, Germany. Available at: http://unfccc.int/resource/docs/convkp/kpeng. pdf.

van Heerden, J., Gerlagh, R., Blignaut, J., Horridge, M., Hess, S. and Mabugu, R. E. E. 2005. "Fighting CO2 pollution and poverty while promoting growth: Searching for triple dividends in South Africa". *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.849245. PREM Working Paper no. 05–02.

Vos, R., W. Martin, and D. Laborde (2020). 'How much will global poverty increase because of COVID-19?'. Downloaded at: https://www.ifpri.org/blog/how-much-will-global-poverty- increase-because-covid-19.

Wang, Q., Hubacek, K., Feng, K., Guo, L., Zhang, K., Xue, J., and Liang, Q. 2019. "Distributional impact of carbon pricing in Chinese provinces". *Energy Economics,* 81: 327–340.

WB (World Bank). 2019. "State and trends of carbon pricing". Washington, DC: World Bank.

WB (World Bank). 2020. Africa's Pulse, No. 21, Spring 2020: An Analysis of Issues Shaping Africa's Economic Future.

WHO (World Health Organization). 2022. WHO Coronavirus (COVID-19) Dashboard, WHO, available on https://covid19.who.int (on January 2022).

Wilkie, D., Wieland, M., Boulet, H., Le Bel, S., van Vliet, N., Cornelis, D., Warnon, V., Nasi, R., Fa, J. 2016. "Eating and conserving bushmeat in Africa," *African Journal of Ecology, Volume 54, Issue 4.*

WTO (World Trade Organization). 2001. Declaration on The Trips Agreement and Public Health, WTO Ministerial Conference Fourth Session, Doha, 9–14 November 2001(WT/MIN(01)/DEC/2)

3

Energy and Climate Change: What Policy Options Exist?

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Introduction

The climate challenge is an energy challenge. The energy sector is responsible for two-thirds (2/3) of total greenhouse gas emissions.[7] Conversely, climate change affects the energy sector. Climate hazards increasing with climate change affect energy supply (damage infrastructure and affect production) and demand (increase heating, cooling, and air conditioning needs). Without appropriate policy design with a holistic view of the energy-climate nexus, this complex and bidirectional relationship can turn into a vicious circle. The solution to the climate challenge will therefore be an energy solution or it will not be.

Energy is a strategic resource for development. It affects every segment of life and livelihoods. Access to modern energy sources contributes to building human capital, especially for women (time reallocation for education and health benefits), enhances productivity, improves technology adoption and uses, lower transportation and communication costs, improves the overall well-being (Toman and Jemelkova, 2003). However, green- house gas emission trends inherent to the current modes of energy consumption show the urgent need to find a solution that reconciles the energy uses to the climate challenge.

While most regions of the world are focusing on finding sustainable energy solutions, Africa is facing two pressing challenges: it must reconcile the imperative of climate change with filling its widening energy gap. Africa is experiencing an enormous and widening energy gap over time (Figure 7). The energy-sector investment is less than 1% of gross domestic product (GDP) compared to 3.4% needed to achieve universal access to electricity (IRENA, IEA, 2011). The current installed power generation capacity in Africa is 147 GW, comparable to the capacity China installs in one or two years, not to mention that half of the power generation capacity in SSA is in South Africa.

As a result, the average per capita electricity consumption in sub-Saharan Africa (excluding South Africa) is just 153 kWh/year corresponding to one-fourth of the con- sumption in India and just 6% of the global average. Nearly 640 million people lack access to electricity. Over the last fifteen years, the per capita energy consumption in Sub-Saharan Africa declined from 30% the level of South Asia, to just 24% (Africa Union Commission, 2017). For instance, the monthly energy use of an American is equivalent to eight years of consumption of the average person in Tanzania. The picture is even worst when considering the access to clean, non-polluting cooking facilities. Sub-Saharan Africa is the only region where the absolute number of people without access to modern energy is rising for both electricity and clean cooking stoves (Africa Union Commission, 2017). The region is not on track to achieving universal access to modern energy by 2030 as targeted by the Sustainable Development Goals. At the current pace, it will take an additional half a century (2080) to achieve this goal. Universal access to clean cooking facilities would not occur in this century.

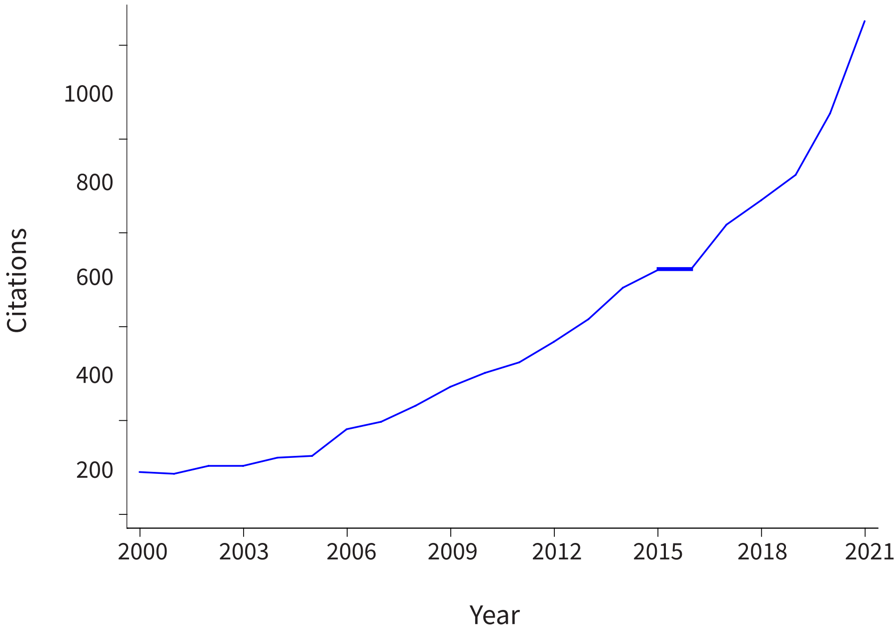
The lack of reliable energy sources has social, economic, and environmental consequences. The energy system in developing countries, in general, and in Africa in particular, is often characterized by, on the one hand, inefficient uses of traditional energy sources such as fuelwood which poses environmental and health issues and, on the other

7 https://www.ipcc.ch/2020/07/31/energy-climatechallenge/

hand, uneven distribution and use of modern energy sources which undermine shared economic and social prosperity, equity and quality of life (Barnes and Floor, 1996). The inefficient energy sources contribute to pollution, environmental degradation (including deforestation) and hence climate change while the widespread lack of modern energy sources undermines the wealth creation needed to cope with climate shocks. About 600,000 people in Sub- Saharan die each year of household air pollution as a consequence of heavy reliance (4 in 5 people) on solid biomass, mainly fuelwood and charcoal for cooking (Africa Union Commission, 2017). Over 80% of primary schools lack access to electricity in many countries across Sub-Saharan Africa (i.e., Burkina Faso, Cameroon, Malawi, and Niger) which hinder children's educational outcomes.

Closing Africa's energy gap in a sustainable way has enormous economic and social benefits. The power shortages and energy sector impediments cost Sub-Saharan Africa between 2 to 5% of GDP annually (IRENA, IEA, 2011; Africa Union Commission, 2017), undermining job creation and investment. On average, business owners report electricity outages as the top constraint to business operation in Africa, ahead of corruption and political instability (Asiedu et al., 2021). How could Africa fill its energy gap while respecting the environment and avoiding the environmental disaster, into which the production and consumption patterns of developed countries have led the world? In any case, the climate peril requires finding sustainable energy solutions that are resilient to climate disruption and extreme weather events, and that meet the growing demand.

Figure 5: Citations in Economics, Econometrics and Finance Journal



Data source: Scopus
Notes: Citations for research terms "climate change" and "energy policy"

The climate change and energy literature experienced exponential growth over the last two decades. Figure 1 shows the evolutions of the citations of the papers published in peer- review journals in economics, econometrics and Finance Journals using the research terms “climate change” and “energy policy”. Nonetheless, the existing research on the subject has produced disparate knowledge often inaccessible to policymakers. This paper aims to capitalize on the extensive knowledge by identifying actionable policy options for better- articulated climate-energy policies with a special focus on Africa. To do so, we undertake a systematic search of the climate change and energy literature using the Scopus database. We propose an analytical framework to elucidate the energy-climate relationship. We complete the analysis with specialized reports from credible international institutions that have a sharp analysis of the subject such as the Intergovernmental Panel on Climate Change, the United Nations Environment Programme, the African Development Bank, the International Atomic Energy Agency, and the Nationally Determined Contributions documents. We find that investing in renewable energy, promoting the transition to a renewable-based energy system, and encouraging improved technologies contribute to closing the energy gap while promoting climate mitigation. Also, policymakers should consider the climate threat when building energy infrastructures.

The remaining of the paper is organized as follow. Section 2 pictures the energy sector in Africa. In sections 3 we describe the methodology for identifying policy options. Sections 4 and 5 present a simple framework to elucidate the energy-climate change nexus and the policy options respectively. Finally, section 6 concludes.

Picturing the energy sector in Africa

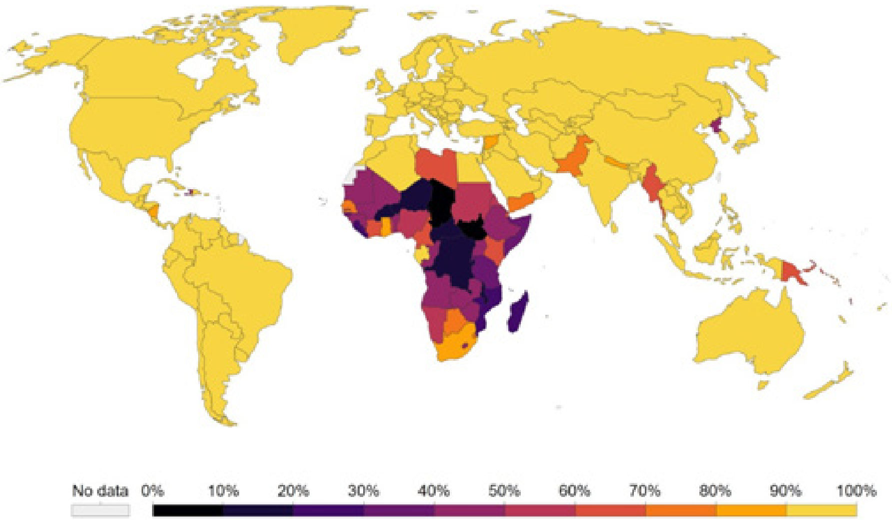
This section provides some facts on energy consumption, energy sources and the correlation between energy consumption and development in Africa.

Energy access and sources in Africa

Africa exhibits a frightening energy gap compared to the rest of the world. Access to reliable electricity remains challenging. The fact that on average electricity outages is the top business constraint ahead of corruption and political instability is eloquent (Asiedu et al., 2021). Figure 6 presents the map of the share of people who have access to electricity around the world in 2019, the latest year the data are available. Even though the national average hides the huge gap between rural and urban area, access to electricity in most African countries are below 40%. Only five countries in Africa (Algeria, Egypt, Gabon, Morocco, and Tunisia) reach electricity access above 90% and among them, only one (Gabon) is in Sub-Saharan Africa. Several countries still have access to electricity below 10%.

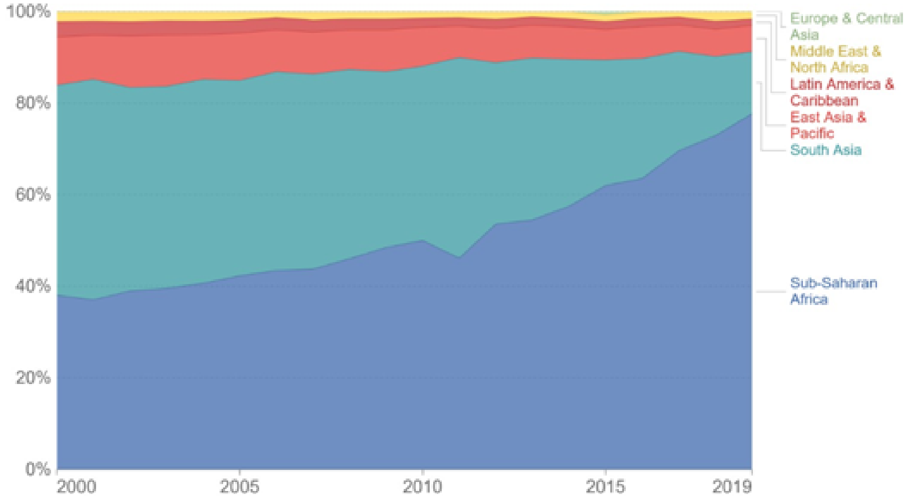
Figure 7 gives a time profile of the share of people living without access to electricity as a share of the world’s population living without access to electricity.

Figure 6: Share of people who have access to electricity in the world in 2019



Source: World Bank

Figure 7: People living without access to electricity as a share of total population

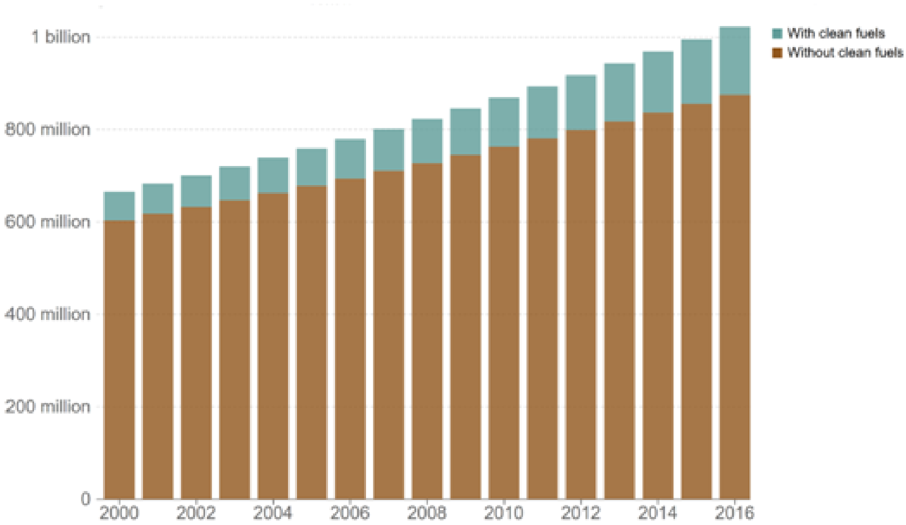


Source: Calculated by Our World in Data based on data published by the World Bank

The striking fact is that despite the efforts to ease access to electricity, Sub-Saharan Africa is the only region where the number of people living without access to electricity as a share of the world's total is increasing. The trend shows a rapid increase from 2010. More than 2/3 of the world population without access to electricity is living in Sub-Saharan Africa. This situation may be related to the increase in population combined with insufficient investment in the energy sector (less than 1% of GDP).

Sources such as oil (38.8% in 2020) and coal (22.16%) are still the dominant source of energy in Africa and their combined share is decreasing mainly driven by coal. The share of natural gas is increasing over time. Hydropower is the major source of renewable energy (6.37%). The share of the other renewable sources such as solar (0.49% in 2020), wind (1.04%) and biofuels are insignificant. African countries should invest in their energy transition regarding the potential for renewable energy and the climate challenge. These investments should consider climate resilience due to potential impacts in the long run.

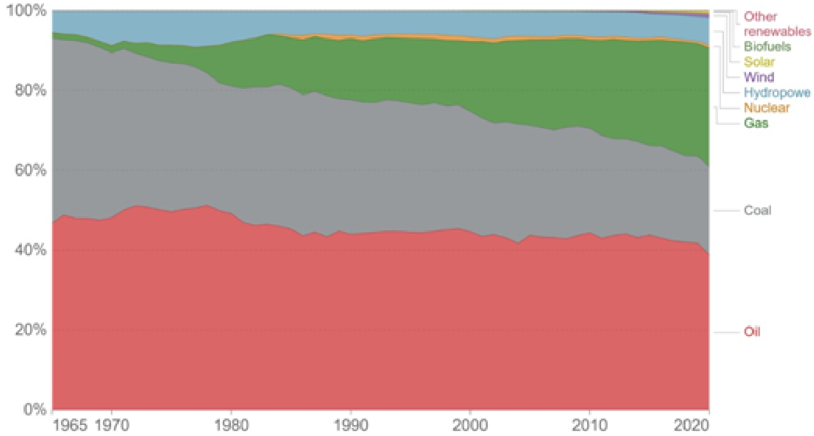
Figure 8: Number of people without access to clean cooking fuel



Source: Our World in Data based on World Bank. World Development Indicators

Figure 8 shows the evolution of the number of people with and without clean fuels in Sub-African. More than eight out of ten people lack access to clean fuels for cooking. The number of people without access to clean cooking fuels is increasing over time as the population increase.

Figure 9: Energy consumption by sources

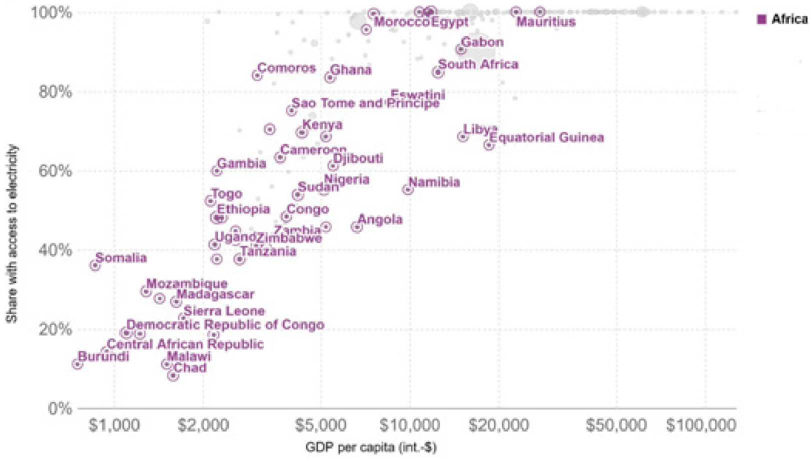


Source: BP Statistics Review of world Energy
Note: 'Other renewable' includes geothermal, biomass and waste enegy.

Energy and development

Access to climate-friendly energy sources is associated with higher GDP per capita in Africa. Figure 10 displays the correlation between access to electricity and GDP per capita for African countries.

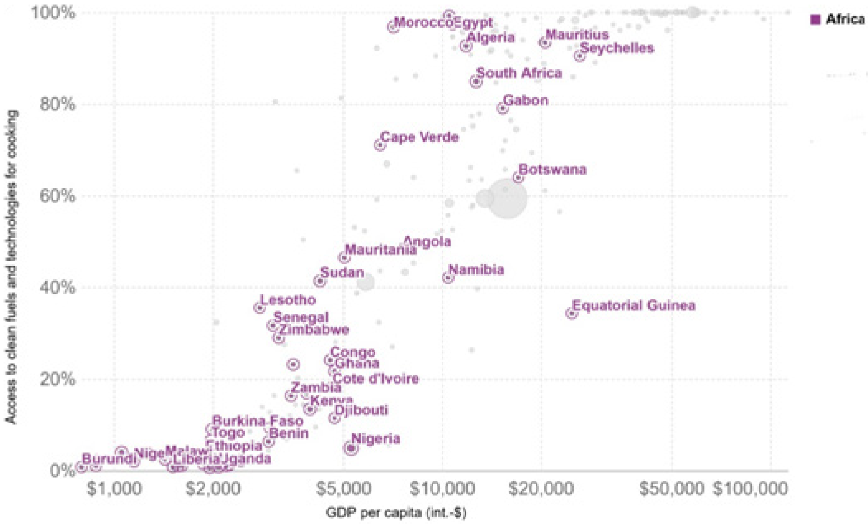
Figure 10: Access to electricity vs. GDP per capita



Source: Data compiled from multiple sources by World Bank
Note: GDP per capita is adjusted for price differences between countries and inflation and measured in international-$

The figure clearly shows that higher GDP per capita is associated with higher electricity consumption. Similarly, Figure 11 shows that access to clean fuels and technologies for cooking is compatible with higher GDP per capita in Africa.

Figure 11: Access to clean fuels for cooking vs. GDP per capita



Source: World Bank

Beyond these simple correlations, considerable evidence in the literature suggests a causal link between energy and growth (Hamit-Haggar, 2016). Apergis and Payne (2009) find that for six Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama) over the period 1980–2004, the Granger-causality test sustains both short-run and long-run causality from energy consumption to economic growth. For African countries, however, Wolde-Rufael (2006) using a sample of 17 countries finds a causality from GDP per capita growth to energy consumption for six countries, from energy consumption to GDP growth for three countries and both directions for three countries. In general, the causality from energy consumption to economic growth seems to be stronger for developed countries than for developing ones.[8] This literature implies that, for countries with wide energy gap, closing sustainably the energy gap and pursuing other development goals may not be conflictual. However, identifying sound and actionable policies for conciliating the climate imperative while addressing the energy gap would be a decisive step. Regarding other socio-economic outcomes, Muchapondwa et al. (2021) using the World Bank Multi-Tier Framework data for Kenya find a positive and significant average, heterogeneous and multi-valued treatment effects of electrification on household welfare outcomes such as household expenditure, household head's employment in the non-agricultural sector, household expenditure on alternatives energy sources and time children spend studying. Most importantly, access to energy increases women and girls

8 See Chontanawat et al. (2008) and Payne (2010) for a survey of this literature

well-being, the time allocated to their education and productivity in developing countries where they are the ones in charge of collecting firewood (Pueyo and Maestre, 2019).

Identifying actionable policy options from the abundant literature is beneficial not only for climate mitigation but also for socio-economic outcomes including economic growth.

Methodology

We use two methods to identify actionable policy options. First, we use the Scopus database to undertake a systematic search in the literature on climate change and energy nexus. We complete this systematic research with a synthesis of reports on climate change and energy from distinguished international organizations.

Web of science and google scholar provide alternative sources with some limitations, however. Google scholar for instance is often criticized for being generous because it includes working papers and conference proceedings. Web of Science on the other hand considers only the papers published in its journal index. The Scopus database is therefore a good comprise between the two extremes.

We identify papers related to energy and climate change in the Scopus database by using the following keywords: “climate change” and “energy policy”. Scopus database considers all papers that have these keywords appear in their title, abstracts, or as key- words. The proposed title of the paper guided the choice of the keywords. As of 10 February 2022, we find at a first step 4 821 papers. When we restrict the sample to the subject of Economics, Econometrics, Finance, the number of papers becomes 352 including 258 journal articles.[9]

Adding Africa drastically reduces the sample to nine documents, so we did not include Africa in the keywords. However, this is a signal that policy-oriented research on the subject is still scant in Africa. Few papers are related to nuclear energy and hence less relevant for the African context regarding the current share of nuclear energy in Africa (0.6% of energy consumption).

The papers cover a transversal issues such as finances and governance (Li et al., 2022; Wijesekere and Syed, 2016) and a range of energy-climate related issues including energy efficiency (Khalil and Khalil, 2015) energy transition and implications (Urban, 2014; Nordhaus, 1993; De La Peña et al., 2022), research and development on new energy technology (van der Zwaan et al., 2016), building resilience (Silvast, 2017). However, the literature on the impacts of climate change on the energy sector is limited. Regarding this limitation, we propose a framework for understanding the relationship between energy and climate change. The literature is recent: the first paper is published in 1993 by Nordhaus (1993) and 41.2% (145 papers) of the papers have been published over the last five years (44 papers in 2021). Attention is paid to the recent years for up-to-date policies. Nordhaus (1993) turn out to be the most influential paper in terms of the number of citations.

Finally, the second method targets specialized reports from credible organizations with sharp knowledge on the subject, such as the Intergovernmental Panel on Climate

9 The full list of papers is available upon request.

Change, the United Nations Environment Programme, the African Development Bank, the International Atomic Energy Agency, and the Nationally Determined Contributions documents to complete the analysis.

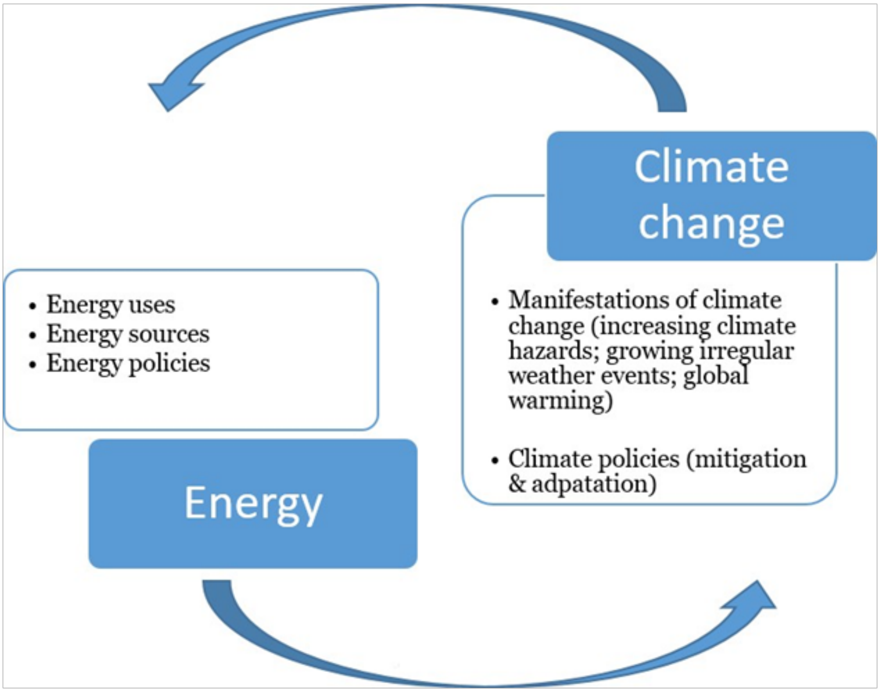
Energy and Climate change: A framework

This section presents a simple analytical framework for the link between energy and climate change. The Energy and climate change debate mostly focuses on one direction relationship and as a result, it often lacks a holistic approach to the climate-energy nexus. The studies on the impact of climate on the energy sector are recent (Ansuategi, 2014).

Figure 12 presents this simplified analytical relationship. It shows that climate change affects the energy sector, as well as the energy sector itself, affects climate change in return.

The energy system affects climate change and how people could respond to it through different mechanisms. The most trivial link between the energy sector climate change is through greenhouse gas emissions. However, access to reliable and affordable energy services contributes to building people's resilience to climate change. People are exposed to climate change in part of a lack of coping mechanisms and this vulnerability increases in return the reliance on scarce resources and hence environmental degradation. The energy sector by reducing poverty and improving health and productivity, enhances competitiveness and promotes economic growth (Perera et al., 2015).

Figure 12: A framework for Energy and Climate Change nexus



While it is well documented that the energy sector contributes to climate change, it is increasingly true that climate change is likely to affect the energy sector. This relationship is shaped by global warming, extreme climate events on the one hand and the policy responses on the other hand. Global warming and increasing extreme climate events affect energy supply and demand through several mechanisms. Rising temperatures reduce the efficiency of power generation, increase demand for cooling, and increase evaporation and drought which in return increase the need for energy-intensive methods of providing drinking and irrigation water. Extreme climate events such as more intense storms, hurricanes and sea-level rise in coastal areas increase the risk of energy supply disruptions. Flooding and intense storms can hamper power lines and energy equipment. Changes to the water cycle impact hydropower.

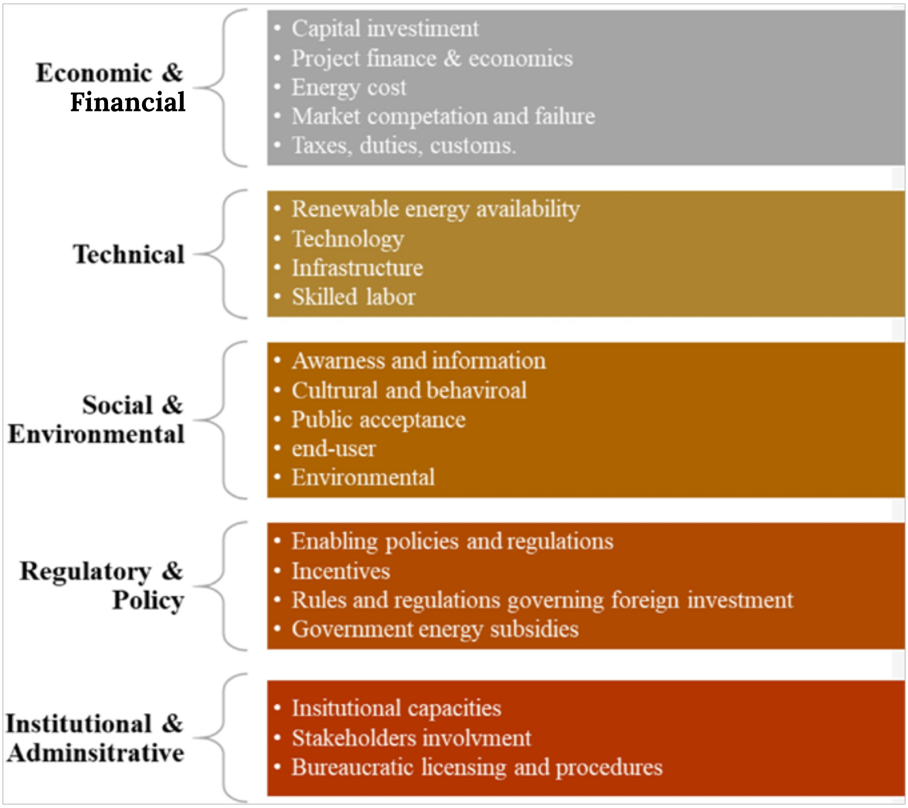
Climate mitigation and adaptation policies often increase the vulnerability of the energy sector to climate change specifically in the long run. For instance, biofuel production is often viewed as a climate mitigation solution (Cheng and Timilsina, 2011; Tirado et al., 2010). However, other issues including food security asides, the shift to biofuels production and dependence on biofuels increase the vulnerability of the energy supply to climatic conditions. Climate change is likely to affect biofuel production through land degradation.

Policy relevant findings and policy options

The policy options identified in the literature revolve around the bidirectional relationship between the energy sector and climate change. On the one hand, these policies are concerned with how to support climate-friendly energy policies and on the other hand, how to build climate-resilient infrastructure; a link often overlooked in the literature. These policy options can be grouped into transversal issues, electrification policies and improved cookstove interventions.

Table 6 summarizes transversal policy options identified in the literature. These policies are related to financing and investment, technology adoption, governance, building efficient and resilient energy systems, and promoting climate-friendly energy sources. They are related to the obstacles to energy transitions often classified into five categories: economic and financial, technical, social, and environmental, regulatory and policy and institutional and administrative. Figure 13 identifies the set of aspects to implement re- forms.

Figure 13: Barriers to renewable energy resources deployment



Source: Olabi and Abdelkareem (2022)

Electrification policies should contribute to close the energy gap specifically in rural area, contribute to mitigating climate change while being resilient to climate change and increase extreme weather events. Tables A1, A2, A3 A4, A5 and A6 describe in details respectively the impacts of climate change (and extreme climate events) and the adaptation policy options by energy sources (thermal power, hydropower, the grid system wind and solar energy).

Table 6: Synthesis of policy options

Policy area	**Policies**
Financing and investment	Set references in renewable energy investment based on best practices
	Encouraging public private partnership Mobilizing both domestic and foreign aid Subsidies for clean energy investment
Technology adoption	Financing research and development
	Accompanying technology adoption programme with sensitization campaigns
	Improving environmental education through mass media and especially educational institutions;
Governance	Encourage cooperation between countries
	A clear and publicly accessible statement of the standards set and agreements reached;
	Strengthen the legal framework Promote business friendly environment
	A means of monitoring and spot-checking pollution
	Fair and equal application of the laws and regulations to all parties.
	A sound local framework for negotiation between stakeholders
Energy efficiency and resilience	Promote behavioural change
	Adopting stringent climate policy can boost innovation in the energy sector
	Consider climate change while building renewable infrastructure
Promoting renewable energy	Incentivize energy-efficiency improvement measures
	Give policy supports to renewable energies that are not yet competitive

Muchapondwa et al. (2021) investigate what we can learn from contemporary electrification policies and past research on the impacts of electrification and how to design and conduct policy-relevant research in the future. They survey the literature on the impact of electrification on social outcomes with a focus on methodology. The authors identify seven policy challenges undermining full access to electrification in Africa. According to Muchapondwa et al. (2021), African governments should: (1) set up the right enabling policy to attract private investors; (2) allocate more funding directed to productive energy investment; (3) adopt energy-efficiency measures; (4) develop bankable projects; (5) take a continental approach to energy infrastructure; (6) implement full-country electrification programs and (7) consider developing countries' characteristics such as resource constraints, supply shortages, the predominance of informal economies, and the preferences of local stakeholders. The main policy implication is that electrification programmes may be more effective when combined with complementary programmes such as those that increase accessibility and affordability.

Alem (2021) surveys studies on factors that promote the adoption of improved and modern cookstoves and their impacts on household outcomes and greenhouse gas emissions. The survey relies only on studies that use rigorous impact evaluation methods such as randomized controlled trials, difference-in-differences, regression discontinuity designs, and instrumental variables methods. Improved cookstoves adoption in addition to being cost-effective (Alem and Hassen, 2020; Gebreegziabher et al., 2018), reduces indoor air pollution and relieve chronic symptoms of respiratory irritation (Bensch and Peters, 2015; Smith-Sivertsen et al., 2009), fuelwood consumption (Adrianzén, 2013; Bensch and Peters, 2015; Gebreegziabher et al., 2018), CO2 emissions (Gebreegziabher et al., 2018; Alem and Hassen, 2020), cooking time and increase income through time reallocation (Alem and Hassen, 2020; Bensch and Peters, 2015). But, how can policymakers promote improved cookstoves adoption and uses?

To answer this question, Alem (2021) highlights 10 rigorous impact evaluation studies on factors that promote improved cookstoves adoptions. The findings and policy implications of these studies are summarized in Table 7. The key takeaway is that financial constraints are the key driver of uptake of appropriately designed improved cookstove (ICS). For the ICS programmes to be effective the design should meet the cooking needs, be culturally accepted and be accompanied by sensitization campaigns including discourag ing the use of traditional stoves (Burwen and Levine, 2012).

Table 7: Synthesis of studies on the drivers of ICS adoption

Papers	Study area	Policy relevant findings
Alem and Ruhinduka (2020)	Tanzania	Liquidity constraint is the key reason for the low adoption rate of modern cookstoves, and micro-credit options that offer convenient re-payment schedules to households would be extremely useful in facilitating transition to modern cooking appliances
Alem et al. (2018)	Ethiopia	Simple income generating opportunities empower women and improve their decision-making ability and willingness to pay (WTP) for new technologies.
Beltramo et al. (2015)	Uganda	They find that marketing messages do not have a statistically significant effect on WTP, but the option to pay over four weeks greatly increased WTP
Bensch and Peters (2015)	Senegal	Learning about the technology compensates for a large part of the reference dependence, and free distribution does not lead to decline in future demand.
Berkouwer and Dean (2020)	Kenya	Provision of credit or subsidy options would allow households to adopt high-return energy-efficient technologies and improve their wel-fare.
Mobarak et al. (2012)	Bangladesh	Information campaigns are very important to increase adoption of ICS to optimal levels, but they should be combined with policies that ad-dress the liquidity constraints of households.
Miller and Mobarak (2013)	Bangladesh	Increasing women decision-making power to make the purchase and incorporating at-tributes that are valued by men into ICS will very likely increase the adoption rate.
Levine et al. (2018)	Uganda	If information and liquidity constraints are addressed, the high start-up cost of new cook- stoves does not necessarily lead to low de- mand.
Miller and Mobarak (2014)	Bangladesh	New technologies should be consistent with local preferences and attributes.
Pattanayak et al. (2019)	India	Subsidizing ICS is indeed important to promote adoption, but to be effective, subsidies should be combined with effective marketing campaigns and robust supply chains.

Concluding remarks

Energy is at the heart of any solution to the thorny climate issue. It affects life and production in many ways. However, the abundance and the disparate nature of literature and the intertwined energy-climate relationship impede the identification of actionable policies. This paper synthesizes existing policies by drawing on both the existing literature and the work of credible international organizations, with a sharp knowledge of the subject, such as the Intergovernmental Panel on Climate Change, the United Nations Environment Programme, the African Development Bank, the International Atomic Energy Agency, and the Nationally Determined Contributions documents. We find that the literature mostly focuses on the impact of energy on climate change and neglects the impact of climate change on the energy sector. Ignoring the importance of building climate resilient energy infrastructure can lead to endless starting point.

References

Adrianzén, M. A. (2013). "Improved cooking stoves and firewood consumption: Quasi- experimental evidence from the northern peruvian andes." *Ecological Economics*, 89:135–143.

Africa Union Commission (2017). Agenda2063-the Africa we want.

Alem, Y. (2021). Mitigating climate change through sustainable technology adoption: Insights from cookstove interventions. AERC Working Paper N°CC-006.

Alem, Y. and Hassen, S. (2020). The impact of improved cookstoves beyond fuel saving: A randomized controlled trial from ethiopia. Technical report, EfD Discussion Paper.

Alem, Y., Hassen, S., and Köhlin, G. (2018). "Decision-making within the household: The role of differences in preference and autonomy". Department of Economics, University of Gothenburg Working Paper.

Alem, Y. and Ruhinduka, R. D. (2020). Saving africa's tropical forests through energy transition: A randomized controlled trial in tanzania. Technical report, Ruhr Economic Papers.

Ansuategi, A. (2014). "Climate change and the energy sector: Impacts and adaptation". In, *Routledge Handbook of the Economics of Climate Change Adaptation*, pages 227–241. Routledge.

Apergis, N. and Payne, J. E. (2009). "Energy consumption and economic growth in cen- tral america: evidence from a panel cointegration and error correction model". *Energy Economics*, 31(2):211–216.

Asiedu, E., Azomahou, T. T., Gaekwad, N. B., and Ouedraogo, M. (2021). "The determinants of electricity constraints by firms in developing countries". *Energy Economics,* 104:105605.

Barnes, D. F. and Floor, W. M. (1996). "Rural energy in developing countries: a challenge for economic development". *Annual Review of Energy and the Environment*, 21(1):497–530.

Beltramo, T., Blalock, G., Levine, D. I., and Simons, A. M. (2015). "The effect of marketing messages and payment over time on willingness to pay for fuel-efficient cookstoves". *Journal of Economic Behavior & Organization*, 118:333–345.

Bensch, G. and Peters, J. (2015). “The intensive margin of technology adoption–experimental evidence on improved cooking stoves in rural senegal”. *Journal of Health Economics*, 42:44–6

Berkouwer, S. B. and Dean, J. T. (2020). Credit and attention in the adoption of profitable energy efficient technologies in kenya.

Burwen, J. and Levine, D. I. (2012). “A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana”. *Energy for Sustainable Development,* 16(3):328–338.

Cheng, J. J. and Timilsina, G. R. (2011). “Status and barriers of advanced biofuel technologies: a review”. *Renewable Energy,* 36(12):3541–3549.

Chontanawat, J., Hunt, L. C., and Pierse, R. (2008). “Does energy consumption cause economic growth?: Evidence from a systematic study of over 100 countries.” *Journal of Policy Modeling,* 30(2):209–220.

De La Peña, L., Guo, R., Cao, X., Ni, X., and Zhang, W. (2022). Accelerating the energy transition to achieve carbon neutrality. *Resources, Conservation and Recycling,* 177:105957.

Gebreegziabher, Z., Beyene, A. D., Bluffstone, R., Martinsson, P., Mekonnen, A., and Toman, M. A. (2018). “Fuel savings, cooking time and user satisfaction with improved biomass cookstoves: Evidence from controlled cooking tests in Ethiopia”. *Resource and Energy Economics,* 52:173–185.

Hamit-Haggar, M. (2016). “Clean energy-growth nexus in sub-saharan africa: Evidence from cross-sectionally dependent heterogeneous panel with structural breaks”. *Renewable and Sustainable Energy Reviews*, 57:1237–1244.

IAEA (2021). *Adapting the Energy Sector to Climate Change*. International Atomic Energy Agency.

IRENA, IEA (2011). Prospects for the African Power Sector. *Scenarios and Strategies for Africa Project.*

Khalil, H. A. E. E. and Khalil, E. E. (2015). *Energy Efficiency in the Urban Environment.* CRC Press.

Levine, D. I., Beltramo, T., Blalock, G., Cotterman, C., and Simons, A. M. (2018). “What impedes efficient adoption of products? evidence from randomized sales offers for fuel-efficient cookstoves in Uganda”. *Journal of the European Economic Association,* 16(6):1850–1880.

Li, Z., Kuo, T.-H., Siao-Yun, W., and Vinh, L. T. (2022). “Role of green finance, volatility, and risk in promoting the investments in renewable energy resources in the post-Covid-19”. *Resources Policy,* 76:102563.

Miller, G. and Mobarak, A. (2013). “Gender difference in preference, intra-household externality and low demand for a new technology: Experimental evidence on improved cookstoves”. NBER Working Paper Series*,(18964)*, pages 1–34.

Miller, G. and Mobarak, A. M. (2014). “Learning about new technologies through social networks: experimental evidence on nontraditional stoves in Bangladesh”. *Marketing Science*, 34(4):480–499.

Mobarak, A. M., Dwivedi, P., Bailis, R., Hildemann, L., and Miller, G. (2012). Low demand for nontraditional cookstove technologies. Proceedings of the National Academy of Sciences*,* 109(27):10815–10820.

Muchapondwa, E., Jeuland, M., and Shimeles, A. (2021). Addressing the challenges of sustainable electrification in africa through comprehensive impact evaluations. AERC Working Paper n°CC-011.

Nordhaus, W. D. (1993). “Rolling the ‘dice’: an optimal transition path for controlling greenhouse gases”. *Resource and Energy Economics,* 15(1):27–50.

Olabi, A. and Abdelkareem, M. A. (2022). “Renewable energy and climate change.” *Renewable and Sustainable Energy Reviews*, 158:112111.

Pattanayak, S. K., Jeuland, M., Lewis, J., Usmani, F., Brooks, N., Bhojvaid, V., Kar, A., Lipinski, L., Morrison, L., Patange, O., et al. (2019). Experimental evidence on promotion of electric and improved biomass cookstoves. Proceedings of the National Academy of Sciences, 116(27):13282–13287.

Payne, J. E. (2010). “Survey of the international evidence on the causal relationship between energy consumption and growth”. *Journal of Economic Studies.*

Perera, N., Boyd, E., Wilkins, G., and Itty, R. P. (2015). Literature review on energy access and adaptation to climate change. Evidence on demand.

Pueyo, A. and Maestre, M. (2019). “Linking energy access, gender, and poverty: A review of the literature on productive uses of energy”. *Energy Research & Social Science,* 53:170–181.

Silvast, A. (2017). *Making Electricity Resilient: Risk and Security in a Liberalized Infrastructure.* Routledge.

Smith-Sivertsen, T., Diaz, E., Pope, D., Lie, R. T., Diaz, A., McCracken, J., Bakke, P., Arana, B., Smith, K. R., and Bruce, N. (2009). “Effect of reducing indoor air pollution on women’s respiratory symptoms and lung function: the respire randomized trial, Guatemala”. *American Journal of Epidemiology*, 170(2):211–220.

Tirado, M., Cohen, M., Aberman, N., Meerman, J., and Thompson, B. (2010). “Addressing the challenges of climate change and biofuel production for food and nutrition security”. *Food Research International*, 43(7):1729–1744.

Toman, M. T. and Jemelkova, B. (2003). “Energy and economic development: an assess- ment of the state of knowledge”. *The Energy Journal,* 24(4).

Urban, F. (2014). *Low carbon transitions for developing countries*. Routledge.

van der Zwaan, B., Kober, T., Calderon, S., Clarke, L., Daenzer, K., Kitous, A., Labriet, M., Lucena, A. F., Octaviano, C., and Di Sbroiavacca, N. (2016). “Energy technology roll-out for climate change mitigation: A multi-model study for Latin America”. *Energy Economics*, 56:526–542.

Wijesekere, G. and Syed, A. (2016). “Energy policy and regional cooperation: Australia’s contribution to low carbon green growth initiatives”. In; *Investing on Low-Carbon Energy Systems*, pages 251–280. Springer.

Wolde-Rufael, Y. (2006). “Electricity consumption and economic growth: a time series experience for 17 African countries”. *Energy Policy*, 34(10):1106–1114.

Appendix

Table A1: Impacts of gradual climate change on thermal power and adaptation options

Impact	Potential vulnerabilities	Adaptation policy options
Higher mean air temperatures	Warmer ambient temperatures reduce the efficiency of thermal conversion.	Select sites in cooler areas to the extent possible. Use non-traditional water sources. Use condenser at the outlet of cooling.
Lower mean precipitation	Less precipitation means less and warmer water for cooling, which reduces cooling efficiency and may reduce power generation	Consider alternative cooling technologies: dry cooling towers, regenerative cooling, heat pipe exchangers
Increased windiness near coasts and dry areas	Airborne salty material from sea can cause corrosion and short circuit electrical equipment Dust and sand blown by wind may cause equipment malfunction	Enclose or cover sensitive equipment
Sea-level rise	Rising sea levels can result in inundation of coastal power plants and related infrastructure	Build new or raise existing dykes and sea walls Relocate existing plants to, and build new plants at, safe sites

Adapted from IAEA (2021)

Table A2: Impacts of extreme weather events on thermal power and adaptation options

Impact options	Potential vulnerabilities	Examples of adaptation
More frequent and intense hot temperatures	Hot spells aggravate the impacts of on average warmer conditions Less conversion and cooling efficiency Overheated buildings	Locate new plants at cooler sites when possible
More frequent and more intense high precipitation events	Extreme high rainfall in a short time can inundate plant site and can lead to coal stockpile drenching Excessive snow can cause weak structures to subside and hinder ac cess to the plant	Change reference climate for drainage design Build proper water management facilities (dams, water pumps) Spray coal to create crusting sur- face or put plant or grass cover on top Reinforce buildings and structures
More frequent and longer periods of low precipitation or drought conditions	Low precipitation leads to reduced water availability and more competition for water Less and warmer cooling water leads to potential reductions in output or even shutdown	Consider alternative cooling options: reuse wastewater and recover evaporated water in recirculating systems Consider dry cooling
More frequent and intense extreme wind conditions (storms, tornadoes, hurricanes)	Windstorms can damage buildings, cooling towers and storage tanks and can disrupt the connection to the grid system	Adjust construction standards to changing conditions Reinforce sensitive buildings and structures Build barriers and windbreaks

continued next page

Table A2 Continued

Impact options	Potential vulnerabilities	Examples of adaptation
Floods in river basins; sea storms in coastal areas	Floods can inundate plant sites, damage buildings and equipment and lead to a shutdown, as well as deluge coal stockpiles and oil and gas storage tanks	Flood protection by dams, embankments Flood control reservoirs, ponds, or channels Drainage improvements and rerouting and isolation of water pipes
Lightning	Lightning can pierce pipelines, dam- age storage tanks and short circuit electric components and connections	Apply enhanced lightning protection Insulate and ground sensitive components Install key components in protected structures or underground

Adapted from IAEA (2021)

Table A3: Impacts Of climate change and extreme weather on hydropower and adaptation options

Impact	Potential vulnerabilities	Examples of adaptation options
Change in precipitation	Amplified by runoff conditions, the resulting change in water availability determines whether power output is reduced or in- creased	Increase storage capacity Adjust water release schedule to maximize generation
Changes in seasonal and interannual variability of precipitation	Higher precipitation variability leads to greater fluctuations in inflows (water availability), which may modify seasonal and annual power output; higher peak flows can cause floods and output losses The resulting floods can dam- age dam walls and turbines directly and indirectly by mobilizing debris in flooded areas up- stream	Improve short term water flow forecasts Adjust water management strategies Build additional storage capacity Enhance turbine runner capacity
Extreme high precipitation events	Floods lead to output losses due to releasing water through by- pass channels	Increase storage capacity and enhance defence structures for dams and turbines. Adjust water management to retain surplus storage for excess water. Organize debris removal
Low precipitation/ high temperature	Both events reduce the amount of water stored	Increase storage capacity, if possible, to retain more water from high flow yields

Table A4: Impacts of gradual climate change on the grid system and adaptation options

Impact	Potential vulnerabilities	Examples of adaptation options
Higher mean temperatures	Warmer temperatures cause increased transmission line losses and the extension of transmission line cables	Consider higher temperatures in the rating calculations for new lines and adjust them in existing lines Manage underneath vegetation to keep it at a distance from cables Consider placing cables underground

Adapted from IAEA (2021)

Table A5: Impacts of climate change and extreme weather on wind energy and adaptation options

Impact	Potential vulnerabilities	Examples of adaptation options
Change in windiness (wind power density)	Windiness determines wind power potential, so any change may modify wind resources	Enhance resource assessment and site selection according to changing conditions
Interannual, seasonal or diurnal variability	Variability determines the timing of power availability	Consider intermittency in energy system planning Build and maintain reserve capacities
Changes in precipitation, thermal regime and near surface humidity	These changes affect the frequency of icing, which causes operation problems and can reduce power output	Account for icing in blade design Install blade heating
Lower air density due to higher air temperature	Lower air density reduces power generation	No adaptation options
Dryer air, causing more windblown dust	Dry air and wind cause dust deposition on blades, which reduces power output	Modify turbine design and blade coatings Increase the frequency of blade cleaning and maintenance

continued next page

Table A5 Continued

Impact	Potential vulnerabilities	Examples of adaptation options
Changes in wave activity and wind–wave coupling	Loads from wind, sea currents, waves and sea ice can cause structural damage to offshore foundations and towers, leading to failures	Adjust design specifications and construction schemes according to projected wave and wind conditions
Wind speed extremes, e.g. sudden change in direction, gust, and shear	Wind extremes increase structural load and threaten the structural integrity of wind turbines, and can cause fatigue and damage to turbine components, leading to reduced out-put	Improve turbine design and apply reinforced structures to withstand extreme wind conditions
Extreme low and high temperatures	Temperature extremes can modify the physical properties (expansion and contraction) of materials and fluid	Install light detection and ranging based technologies to increase protection Consider extreme temperature ranges in turbine mate- rial and lubricant selection
Changing lightning frequency	Lightning can damage blades and mechanical and electrical components	Apply enhanced lightning protection and grounding

Adapted from IAEA (2021)

Table A6: Impacts of climate change and extreme weather on and adaptation options for solar energy

Impact	Potential vulnerabilities	Examples of adaptation options
Higher mean temperatures	Average warmer temperatures improve the efficiency of solar heating (especially in colder regions) but reduce the conversion performance of photovoltaic. Exposure to heat over the long term causes faster material ageing.	Depending on the ratio of value of lost electricity and the costs of alternative cooling options, install cooling facilities to reduce efficiency losses
Changing cloudiness	Increasing cloud cover degrades the performance and reduces the output of all types of solar technology. Decreasing cloud cover is beneficial (increased output)	Cover photovoltaic panels with a rough surface so that they can use diffuse light better. Adjust the angle of fixed mounting to improve the use of diffuse light. Install tracking systems to optimize the angle for diffuse light conditions.
Hot spells cause	Extreme hot temperatures Material damage to photovoltaic panels and reduce power generation	Install passive cooling (natural air flows) for photovoltaic panels or apply active cooling by forced air or liquid coolants

continued next page

Table A6 Continued

Impact	Potential vulnerabilities	Examples of adaptation options
Windstorms	High winds can cause material damage through wind load for all solar technologies Debris carried by wind can impair collector surface areas	Reinforce mounting and supporting structures Fortify sensitive collector surfaces
Wind and sandstorms	Storms can carry and deposit dust and sand on collector surfaces and thus reduce power out-put Higher humidity can make this impact worse	Install a tracking system to rotate panels out of wind Clean collector surfaces Apply elastomeric coatings instead of glass Clean mirrors after storms
Hail	Depending on the size of hailstones, solar heating can suffer material damage Hail can also fracture glass plate cover and inflict damage on photoactive material	Use reinforced glass for flat plate collectors to withstand hailstones Strengthen the surface of evacuated tube collectors Increase protection of all solar equipment beyond current standards
Lightning	Lightning can damage the inverter in photovoltaic panels	Increase lightning protection of the site and the panels

Adapted from IAEA (2021)

4

Urbanization and Climate Change Vulnerability: What Next?

Kamgnia Bernadette Dia

Introduction

Globally, higher agricultural productivity, industrialization, and services stimulated by a growing middle class and foreign direct investment in urban corridors, should all create real ways to generate economic growth in developing countries.

In Africa, the population living in cities doubled from 1995, reaching 472 million in 2015, expecting about 56% of Africans to live in cities by 2050 (Mayaki et al., 2016[10]). Such an urbanization dynamism is neatly pointed out by Garschagen and Romero-Lankao (2013), in their assigning African countries into global urbanization patterns and national income classes. Most of the African countries fell into classes of very high (2) to medium-high urbanization (12) and/or high (7) to medium urban growth (26). For instance, Gabon and Djibouti evolve among countries of “very high urbanization, middle income, medium to low urban growth, low to very high GDP growth”, whereas Angola, Cameroon, Congo (Rep.), Cote d’Ivoire, Ghana, Sao Tome, and Principe are among countries of “medium-high urbanization, middle income, high urban growth, medium to very high GDP growth”. Algeria, Botswana, Cape Verde, Morocco, South Africa, and Tunisia are classified as countries with “medium-high urbanization, middle income, low to medium urban growth, low to very high GDP growth”. Egypt, Lesotho, Mauritius, Namibia, Nigeria, Senegal, and Zambia are among countries of “moderate urbanization, middle income, high to low urban growth, very high to high GDP growth”. Twenty-six (26) African countries are among the 34 countries making up the group of “moderate to medium-high urbanization, low income, high to medium urban growth, low to very high GDP growth” countries. Economic growth was not negligeable in some of the classes. The compelling growing demand in African cities then should translate into tremendous investment in urban infrastructure to be met by 2050; hence support the required structural transformation for Africa’s economic growth.

African cities might be growing due to the massive departure from rural areas coupled with the growing devastating effect of climate change. In effect, agricultural and pastoral activities, that are mainly dependent on rainwater resources, are growing vulnerable to changes in rainfall patterns. Unable to adapt to the risks of climate change and to manage climate variability or develop a good capacity of adaptation, farmers in rural areas have to adopt new behaviors to ensure their development (Kamgnia and Djezou, 2021). A common response was the migration from rural areas (mainly landlocked, and agricultural) to urban areas (mainly coastal, and industrial) in search of well-being (Marchetta et al., 2021; Mbaye et al., 2021; Mpandeli et al., 2020).

Of course, Marchetta et al. (2021) find that the occurrence of drought induces a decrease in rural migration, whereas cyclones do not affect the migration decision. But the longitudinal nature of their data base allowed them to be specific on the fact that the effect induced by drought is not immediate but delayed for about one year

10 Mayaki A.I., Bossard L. & Pezzini M. (2016), “Where cities can take Africa?”, in OECD Observer No 307 Q3, https://oecdobserver.org/news/printpage.php/aid/5629/Where_cities_can_take_Africa.html

after the drought event. The authors specifically claim that the driving mechanism of this effect is the income reduction due to the drop in productivity caused by drought; especially in a country like Madagascar, dominated by rainfed agriculture, where a drop in income would make the cost of migration less affordable for rural households. Along the same line of thinking, Hoffmann (2020) indicates that environmental migration was most pronounced in agriculturally dependent and middle-income contexts where populations have sufficient resources to migrate. Mbaye et al. (2021), on their part, underscored that the large exodus of important numbers of rural residents into African cities is due to higher poverty incidence in African villages, low productivity levels of activities, low access to quality education and healthcare, in rural areas, compared to wellbeing propensities in urban dwellings. Mpandeli et al. (2020), rather, address the issue of climate-induced migration as an adaptation strategy. They specifically looked at the phenomenon from the angle that its planification, coordination, and integration could be 'part of everyone's history, hence contribute to build the societies we are all part of today'.

But cities are not always the solution for departing rural dwellers. Indeed, many rural-urban migrants arrive in cities without the necessary resources to access neighborhoods with quality water, sanitation, and public services. Rather, they find themselves confined in informal settlements on marginalized land, and often in the riskiest areas of the cities. The number of those populations tends to be exacerbated by the growing climate migration. Mbaye et al. (2021) discussed some of the channels through which climate change and environmental degradation impacted migration in West Africa, and how these contributed to increase the exposure of coastal communities to sea level rise in the region.

In effect, it has been echoed that, since the mid-2000, African cities are facing a variety of serious climate whose future trends, severity, and magnitude are rather uncertain. That is notably the case of coastal cities that are highly vulnerable to the climate impacts of sea level rise and storm surges, whereas inland cities face impacts of flooding, droughts, and extreme climatic events (Lwasa and Kadilo, 2010). Those threats are also discussed by Mbaye et al. (2021), indicating that continued sea surface warming would be expected to provoke more tropical cyclones, higher windspeeds, and heavier precipitations. These authors further indicated that a 100 cm sea level rise, accompanied by a 10% intensification of storm surges, increases the potential inundation area to 13.3%, while affecting 31 million more people from baseline scenario, and increase GDP loss to 12.92% from 6.95% in baseline scenario. For instance, in Côte d'Ivoire, exposed coastal areas will increase by 285.2%.

Unfortunately, those climate change vulnerabilities tend to be exacerbated by urbanization. Indeed, using spatial analysis techniques, Mortoja, and Yigitcanlar (2020) showed how peri-urbanization triggers climate change vulnerabilities, in the case of Dakha megacity in Bangladesh. Following these authors, the urban triggered-climate vulnerabilities occur when in the overall urbanization process, major metropolitan cities and regions across countries are gradually expanded by continuously encroaching their physical growth boundaries into adjoining peri-urban areas. Obviously, the landscape of African urbanization features that of a peri-urbanization. One might join Bai et al.

(2017) to admit that the impacts of urbanization on the environment are profound, multifaceted and are manifested at the local, regional, and global scale. These include air pollution, ecosystems, land use, biogeochemical cycles and water pollution, solid waste management, and the climate.

Hence, understanding the linkages between urbanization and climate change vulnerabilities should help address the necessary mechanism for mitigating their coordinated effects. The general objective of the current paper was to analyze policy options for coping with urbanization and climate change vulnerabilities in Sub-Saharan Africa. The specific objectives were to: (i) provide a synthesis of urbanization and climate change vulnerabilities, (ii) quantify the interactions between urbanization and climate variabilities, (iii) define a framework for effective mitigation and adaptation strategies of urbanization and climate change vulnerabilities.

Overall, the specific objectives are achieved based on a combination of a semi-systematic review of selected AERC studies, among others, and of a panel VAR analysis. According to Snyder (2019), a literature review undertaken as a research methodology follows three broad approaches: systematic review, semi-systematic review, and integrative review. Systematic reviews proceed to "synthesize research findings in a systematic, transparent, and reproducible way". Semi-systematic or narrative reviews apply in cases where "topics have been conceptualized differently and studied by various groups of researchers within diverse disciplines, such that a systematic review of every considered article is cumbersome. An integrative or critical review aims to assess, critique, and synthesize the literature on a research topic in a way that enables new theoretical frameworks and perspectives to emerge" (Snyder, 2019).

The AERC committed itself, through the current version of its "Senior Policy Seminars" (SPS), to "assist policy makers and other actors understand better the impacts of climate change on growth and inform policies on building and strengthening resilience (climate proofing) of sub-Saharan African countries to ensure sustainability of growth and development". Hence the 24^{th} SPS served to disseminate to senior African policy makers the findings of several studies prepared by AERC researchers, with support from the Norwegian Agency for Development Cooperation (NORAD). Specifically, AERC selected studies are synthetized under key themes making up a considered SPS.

The current theme, "Urbanization and Climate Change Vulnerability. What next?", synthesized, among others, five studies: (i) Climate Variability and Urbanization in Sub-Saharan Africa: Mitigating the Effects on Economic Growth (Kamgnia and Djezou, 2021); (ii) Heterogeneity in Migration Responses to Climate Shocks: Evidence from Madagascar (Marchetta et al., 2021); (iii) Climate Change and Migration in West African Coastal Zones (Mbaye et al., 2021); (iv) Climate variability, Internal Migration and Household Welfare among Agricultural Households in Tanzania (Chegere and Mrosso, 2021); (v) Extreme Climate Events and Conflicts: The Case of G5-Sahel Countries (Ouédraogo, 2021). These studies contributed differently to the various components of the interaction between urbanization and climate variability, whereas their dissemination should encompass the various aspects of the theme that they analyzed. Hence, a semi-systematic review, rather than a systematic review of each one of the considered studies, was undertaken. The PVAR approach is fully presented in the third section of the paper.

Following the introduction, section 2 presents the synthesis of the interactions between urbanization and climate change vulnerabilities, whereas the evidence of the interlinkages between the two phenomena is examined in section 3. Section 4 discusses a framework for designing strategies to cope with the identified interlinkages.

Urbanization and Climate Change Vulnerabilities: a synthesis

Urbanization pushes to environmental changes, whereas climate events lead to vulnerabilities, all in various ways. Based on a review of selected literature, these effects are discussed then synthetized.

Urbanization, a push factor to environmental changes

Urbanization often is directly linked to the degradation of environmental quality, including quality of water, air, and noise. Specifically, modifications in natural surfaces increase urban heat island, to further exacerbate increases in global temperatures associated with climate change (Cullis et al., 2021; Bobylev et al., 2016; Zhang, 2016; Liang, 2011).

In other words, increasing urbanization creates microclimates where temperatures increase because of the urban heat island effect. Indeed, urban expansion is linked to a substantial demand for natural resources from urban producers and consumers, thus transforms the urban environment. As cities continue to expand, spaces are devasted, along with earth squash, what multiplies environmental damages, and threatens the biodiversity. Moreover, the spread of cities reinforces dependence on transportation devices that are high consumers of fossil fuel, with the corollary of an increase in carbon dioxide (CO2) emissions, the main greenhouse gas responsible for global warming.

Moreover, Watkins and Griffith (2015) indicated that the expansion of cities, coupled with the “nutrition transition” (higher consumption and production of meat, vegetable oils, sweeteners, and processed carbohydrates), is driving global changes in water and energy use, land conversion, and ecosystems, thus further constrains water availability. Grimm et al. (2008), on their part, addressed the issue in terms of several characteristics of urban environments that alter energy-budget parameters, to further affect the formation of heat islands (UHI). These include land-cover pattern, city size (usually related to urban population size), increased impervious surfaces (low albedo, high heat capacity), reduced areas covered by vegetation and water (reduced heat loss due to evaporative cooling), increased surface areas for absorbing solar energy due to multistory buildings, and canyon-like heat-trapping morphology of high-rises.

In short, urban surface materials and morphology, as well as emissions from domestic, commercial, and transportation activities, cause local climate changes that are often greater than predicted global climate changes. The implied climatic changes create heat waves and air pollution. Indeed, the effects of reflective power of numerous buildings in urban areas, asphalt roads, coupled with the emissions of transport heat, create an intensification of the temperature, mostly at nights.

Climatic-prone urban vulnerabilities

African cities face a variety of serious climate impacts whose future trends, severity and magnitude are uncertain (IPCC, 2007). Three typical cases are (i) coastal hazards, (ii) inland threats, and (iii) risks in mountainous cities.

Coastal hazards

Sea level rise, and storm surges have grown to become permanent threats to the development of coastal cities. Niger and Nile river deltas are believed to be two of the most exposed locations to coastal hazards, beyond coastal cities of Western Africa, and islands such as Madagascar.

In effect, throughout the 20th century, average temperature has increased by 0.76°C, and global warming accelerated since 1976 to achieve 0.18°C per decade. For tropical waters, the increase has reached 1.2°C, thus defining African coastal areas among the most exposed to sea level rise in the world (Mbaye et al. (2021).

Marine flooding is not the least. Of course, the phenomenon tends to be more frequent in large cities of developed countries than in developing countries. But it is more accentuated in the coastal cities of developing counties, including Sub-Saharan Africa, because of the increasingly numerous urban populations. Increased populations contribute largely to the coastal erosion and marine flooding, two extreme climate events that cause material and human damage, as well as displacement of thousands of people. These can also trigger losses of coastal resources that are key determinants of the local economy, as discussed by Mbaye et al. (2021).

Inland vulnerabilities

Flooding, droughts, storms, scarcity of water, biodiversity loss and heat hinder sustainability in the development of socio-economic activities in inland cities. In effect, the increase in extreme rainfall events enhances the risk of flooding in certain urban areas deemed risky, whereas heavy precipitations often lead to huge landslides, especially in informal and/or precarious urban areas. All these phenomena lead to sustained urban vulnerability.

For instance, following OCHA (2020), flooding has affected 2.7 million people in 18 countries in West and Central Africa, with many regions recording excess rainfalls in 2020. The impact has been particularly severe, and the number of people affected is more than double in 2019, when floods affected 1.1 million people in 11 countries. Houses, goods, crops, and fields have been destroyed. Those massive destructions, coupled with land degradation, further threaten the livelihoods of communities, notably those mainly involved in agriculture.

Still OCHA, in its Floods and Locust Outbreak Snapshot (2020), indicates that heavy rainfall intensified across large swathes of Eastern Africa, causing death, displacement, flooding, landslides and damage to homes, infrastructure and livelihoods. With water levels rising in multiple locations across the region, rivers burst their banks and lakes overflowed. In Uganda, Lake Victoria's water levels were the highest recorded since 1964—more than 50 years ago—according to authorities, causing displacement of communities close to the shoreline and creating challenges for the country's hydropower infrastructure. Southern African regions were no better as far as flooding was concerned. For instance, it was reported that hundreds of homes had been washed away in the iron-roof informal settlements of the Mdantsane township[11].

Indeed, informal, or precarious neighborhoods in cities face climatic-prone risks. In large cities of developing countries, including Sub-Saharan Africa, several precarious neighborhoods have emerged, mostly on high-risk sites, facing a good deal of floods and landslides, resulting in considerable material and human damages. Above all, the poor quality of constructions, coupled with the lack of sanitation, make the residents systematic targets to floods and to other climatic phenomena.

In sum, recalling that more than 70% of the planet's surface is water, as the world warms from increased urban activities, more water evaporates from oceans, lakes, and soils. Hence, when weather patterns lead to heavy rain, more moisture develops to support even stronger heavy precipitations, thus increase the risk and severity of flooding.

Climatic risks in mountainous cities

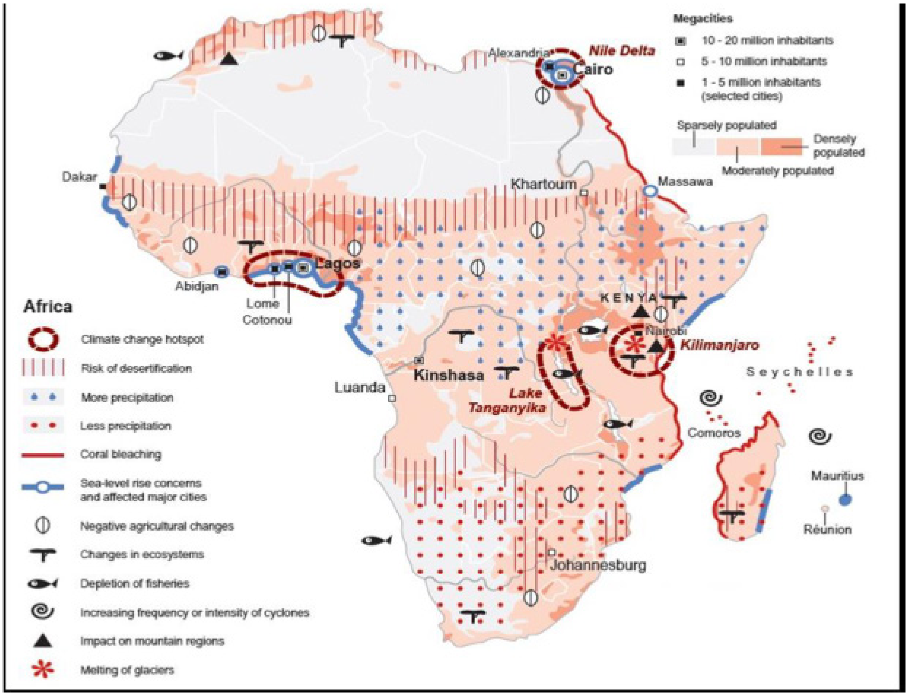
Following Kohler et al. (2014), warming of temperatures, water scarcity, and biodiversity loss are threatening mountainous and highland cities, due to severe climate change. Specifically, due to changing seasonal precipitation patterns and increasing rainfall at the expense of snowfall, freshwater resources might become scarce, even in those regions expected to receive higher rainfall, such as East Africa.

Also, extreme events such as storms, landslides, avalanches and rockfalls may become more common and intense in mountain areas. One would not omit direct human pressure on mountain resources such as land and minerals which are also threatening biodiversity. In effect, the increase in urban expansion results in considerable loss of habitats in key biodiversity hotspots. Thus, the impacts of climate change on mountainous regions should be made a global concern.

Figure 14 summarizes the effects of mass urbanization coupled with climate change. These are numerous risks and impacts (droughts, cyclones, desertification, wildfires), as well as consequences (degradation of fisheries and loss of biodiversity, agriculture seasonal changes, depletion of water resources and limited ecosystem services), straddling the entire continent. But, the resulting socio-economic changes (vulnerable communities, major cities, and densely populated regions prone to sea-level rise and other hazards), and their impacts on migration in Africa, including climate change hotspots, are not the least.

11 https://www.trtworld.com/africa/hundreds-left-homeless-as-floods-sweep-eastern-south-africa-53491

Figure 14: Climatic risks and impacts, consequences, socio-economic changes, and implication for migration.



Source: Mpandeli et al. (2020)

Socio-economic vulnerability to climate change

Increasing urbanization, in coordination with extreme climatic events such as droughts, floods and tropical storms resulting from global warming, affects socio-economic activities in many ways. For instance, tropical countries, including those in Sub-Saharan Africa, are the scene of many of the most stubborn diseases such as malaria, which increase the costs of medical care, and undermine the productivity of workers (Koudjoum and Egbendewe, 2019). Also, the increase in temperature underlying hot climates exacerbates the arduousness of the work of the poor, hence reduces their productivity. Barbier and Hochard (2018) underscored the existence of a poverty-environment trap induced by global warming and lack of care in hygienic cleanliness in developing countries. However, in the current synthesis, an emphasis is put on conflicts and climate induced migration, underscoring the interactions between the two phenomena.

Persistent climatic conflicts

Several arguments, including those of the neo-Malthusians, and the psychologists, have highlighted the direct and indirect link between climate change and social conflicts. Along those lines, Devlin, and Hendrix (2014) indicated that intra- and inter-state conflicts more often derive from climate-prone scarcity of resources such as land and drinking water. Specifically, these authors underscored how harsh and extreme climate phenomena led to cases of insurrections, social instability and other forms of violence leading to loss of human life and destruction of properties.

Nevertheless, the debates on the links between climate change and conflicts remain pendant, as underscored by Ouédraogo (2021). Based on a thorough discussion of the ongoing controversies, this author sought to contribute to the literature in three ways, focusing on the case of G5-Sahel countries: (i) as the first study to investigate the relationship between extreme climate events and conflicts in the G5 Sahel region; (ii) in providing a comprehensive review of the most recent literature on climate change and conflicts in Africa with the aim to nourish the state of knowledge on the subject, and (iii) corroborating empirically to the ongoing debate. Ouédraogo's review of literature pointed to several facts supporting climatic conflicts. The first batch of facts centers on the environmental scarcity that extreme climate events generate, either through environmental degradation (supply induced scarcity), or through an increased demand (demand-induced scarcity), or simply because of lack of endowment (structural scarcity). The interaction between those forms of scarcity leads to the second sets of conflict leading facts that are: resource capture (at the expense of weakest groups), and ecological marginalization (by all means, including violence). The third group of climatic conflict fact comprises the indirect sources of conflict that emanate from extreme climate events. Ouédraogo (2021) specifically points to indirect pathways which he termed "mediating factors". These include government revenue loss due to climate shock; increased human vulnerability in the face of increased food prices and pervasive inequality; disaster mismanagement; resource scarcity, and migration.

On an empirical basis, Ouédraogo pinpointed to a fast-growing rich literature on the interaction between climate change and conflicts over the last two decades. Yet, the empirical debate remains as controversial as the conceptual analyses, opposing adepts of a positive relation between climate events and conflicts, to those of no evidence, even to those sustaining a context-dependent relation. He specifically quoted Buhaug (2015) on his statement that the "ten years of generalizable quantitative research on climate change and armed conflict appears to have produced more confusion than knowledge". But in the specific case of the G5-Sahel countries, using a random-effects probit model over the period 1990-2017, Ouédrago (2021) contributed to three findings. First, extreme climate events increase the risk of social conflicts by 9% the same year, and 13% the next year, surprisingly due to flooding conditions, rather than drought. Second, there is no evidence as concerns armed conflicts resulting in at least 25 battle-related deaths a year. Third, indirect factors such as economic or institutional events do not contribute to the risk of social conflicts in the G5-Sahel countries. The conclusion of this author is that extreme climate events are associated with spontaneous social unrest rather than armed and organized conflicts in the Sahel.

Climate induced migration

Climatic conflicts, coupled with violence such as human rights abuse, genocide, politicide or ethnic cleansing, end up supporting decisions to migrate either internally or overseas (Mbaye et al., 2021). Indeed, one of the mechanisms for dealing with the loss of livelihoods due to climate change is migration out of affected areas (Marchetta, 2021; Rigaud et al., 2018). According to UNHCR (2021), each year, about 20 million people leave their homes to different areas of their country and more migrate internationally due to natural disasters such as prolonged droughts, abnormal heavy rains or rising sea levels, and cyclones. That is the specific case of Madagascar that went through its fifth cyclone, on 22 February 2022, in six weeks. The heavy rain and destructive wind blowing into Madagascar from the Indian Ocean led to the displacement of several populations over six regions. On a continental level, over the period 2000-2017, major migration hubs were Abidjan in Côte d'Ivoire, Johannesburg in South Africa, and Nairobi in Kenya; whereas in the greater Eastern Africa, migration trends indicated that South Africa absorbed the largest number of migrants (2.4 million) followed by the Democratic Republic of the Congo (447,000) and Zimbabwe (361,000), as reported by Mpandeli et al. (2020).

But globally, climate change rather accelerates the pace of rural-urban migration (Mukhopadhyay and Revi, 2009). This point is well shared by Mbaye et al. (2021), Marchetta et al. (2021), and Chegere and Mrosso (2021).

For Mbaye and co-authors, natural disasters, in coordination with ostracism, and lack of educational opportunities, social amenities and recreational activities in the rural areas push people to move to wealthier areas, notably in cities. Of course, the authors report that Feng and Oppenheimer (2012), Hunter et al. (2014), found a link between precipitation and Mexico-US migration, among those who support the existence of a link between the two phenomena. But most of the existing literature remain highly inconclusive about the existence of a causal link between climate change and violence, or migration. Moreover, Mbaye et collaborators indicate that understanding migration drivers and dynamics in general is difficult for several reasons. These reasons include, among others, non-convergent projections on future climate trends; many different phenomena comprising the concept of migration, as well as migration on its own, which can be short-termed or permanent, seasonal, or circular, voluntary, or forced. In short, given the many different layers of drivers of migration, often intertwined, it is not easy to isolate climate change as one single determinant. However, Mbaye et al. (2021) provided a synopsis of relevant frameworks for empirical evidence of climate induced migration. Such frameworks included household decision making process, choice-centered models, gravity models, agent-based models, household allocation models, and more ad hoc models, for predicting migration decisions.

One such model was used by Marchetta et al. (2021) to analyze the impact of climate events on migration among a cohort of young adults residing in rural Madagascar. These authors specifically contribute to the literature on the internal migration response to climate change in Africa, in the case of Madagascar, an island mostly agriculture-dependent, with a fragile ecosystem, where there is a high frequency of weather shocks. A key fact of livelihoods in Madagascar is that adverse climatic events tend to be exacerbated not just by the loss of household incomes, already critically low even in good years, but because of households' coping mechanisms that are limited. Marchetta and collaborators neatly modeled individuals' response to that fact, using an appropriate modeling scheme, which they evaluated on robust econometric approaches, to arrive at three key findings. First, drought strongly and negatively impacts on the decision of youth to migrate in the year after the adverse weather shock, yet with a strong attenuation effect of household assets and access to savings institutions. Second, households that report more social connections outside their villages are more likely to have their young adult members migrate. Third, males, in contrast, are more likely to migrate in search of employment, which often has higher economic returns than migration motivated by marriage and education. Overall, the findings suggest that binding liquidity constraints from climate shocks rather prevent youth migration in rural Madagascar.

Likewise, Chigere and Mrosso used three waves of the Tanzania National Panel Survey data - 2008/09, 2010/11, and 2012/13 – to analyze seasonal internal migration. They specifically looked at migration in its extent either of being a channel that farmers use to respond to climate risk, or whether climate variability is a driving factor for internal migration among agricultural households; else, whether migration shields farmers from agricultural shocks. The main findings of these authors were threefold. First, the rate of seasonal internal migration has been steadily increasing and it is higher among the working population age. Second, the rate of migration is higher among those who are engaged in education and most of those who migrate have no jobs, but they tend to have higher education; within households, heads and their spouses are less likely. Third, climate variability, measured by deviations of the current level of rainfall from the long-term and medium-term means does not have significant effect on migration.

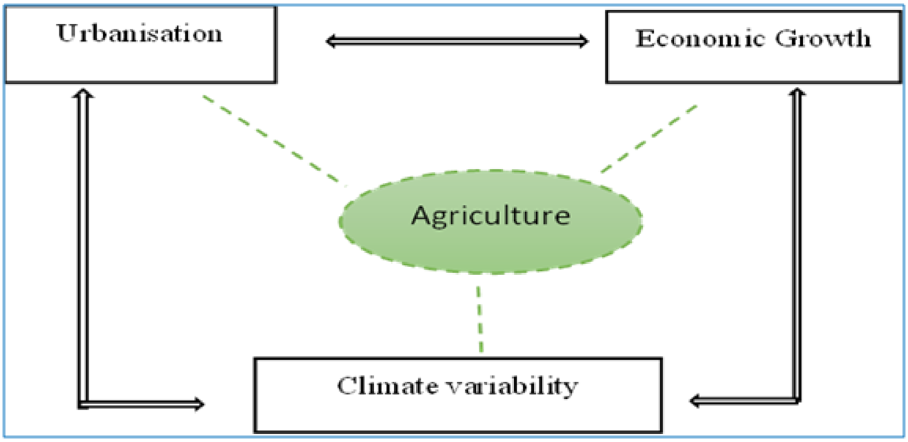
Interactions between urbanization and climate variability: empirical evidence

The above discussion and findings point to the existence of interlinkages between urbanization and climate variability, and implied vulnerabilities. Empirical evidence of those linkages required the mobilization of pieces of information on the economic motivations for migration, especially from rural to urban areas, including agricultural productivity and economic growth. Following a brief discussion of the conceptual framework, the empirical strategy is specified, leading to key results on the evidence of interlinkages between urbanization and climate variability.

Conceptual framework

Whether internal or external, the thinking is that migration movements are more guided by the ability of the receiving area to absorb the labor or further improve the living conditions of migrants. Along those lines, Cattaneo and Peri (2016) showed that high temperatures increase the probability of migration to urban areas in middle-income countries, but that these increases have the opposite effect in poor countries. Thus, the high temperatures observed in the Sahel countries, for example, could lead to large waves of migrants to middle-income African countries (Côte d'Ivoire, Senegal, Ghana, etc.) or European countries. This finding is also reinforced by the findings of Henderson et al. (2017) who pointed out that negative weather shocks only lead to migration from rural to urban areas where the manufacturing sector is well developed and therefore able to absorb surplus labor from vulnerable agricultural areas. Figure 15 presents some of the key interlinkages.

Figure 15: Transmissions channels between climate change, urbanization and economic growth



Note: indicates bidimensional links; indirect effects
Source: Adapted from Kamgnia and Djezou (September 2020)

Agriculture falls at the center of the envisioned interactions for the following reasons. First, most Sub-Saharan African economies are agriculture dependent. Second, depressed agricultural conditions push rural populations to urban areas, as thoroughly discussed in the current paper. Third, the effect of agriculture on climate change might not be so obvious. But the extensive agricultural practices in SSA are deemed to exacerbate the effect of climate change. All the three sets of reasons lead to temperature hikes that depress agriculture with implied effects on economic growth and urbanization. One would expect these interactions to be more pronounced in Sahelian countries than coastal ones, whereas they might not hold in mineral economies in SSA as increase in artisanal mining can be a coping strategy for climate change induced crop failure.

Empirical model

Kamgnia and Djezou (2020)'s review of literature led to a multivariate analysis, simultaneously considering the three variables, as an appropriate empirical framework for a sound understanding of the relationship between urbanization, climate variability and economic growth. The authors therefore fitted a PSTR model and determined a climate threshold of -0.450 at which the relationship between economic growth and urbanization is a virtuous one in Sub-Saharan Africa. With a mean temperature variability of 0.5470, a value well above the empirical minimum threshold of -0.450, the authors confirmed a negative relationship between urbanization and economic growth in the region. But globally, a structural equations model (Sargan 1958; Zheng et al, 2017) could have best fitted the analysis of the interactions between urbanization, climate change, and economic growth. Unfortunately, the structure of the data on the variables of interest, as concerns Sub-Saharan Africa, lacks suitable time series data points for several countries.

In practice, few studies consider climate variability as an endogenous variable in interlinkages analyses. However, given the vulnerability of Sub-Saharan African economies due to their high dependence on the agricultural sector, while facing a rapid urban growth, it appeared inappropriate to consider climate variability as exogenous. Indeed, temperature and precipitation are likely to be endogenous due to individuals' ability to influence their variability, as pointed out by Ebeke and Mireille (202), Shahin et al. (2014). Such a concern is largely documented in the previous section. That is, urban agglomerations contribute to an expansion of heat islands due to the high level of transport, air conditioning, industries, etc. (Brunet, 2016; Alberti 2008; Gaston et al., 2010), resulting in increases in water stress and air concentrations of pollutants, which affect the health of the population (Hirsch, 2017). This deterioration in their health can have a negative impact on the population’s ability to work and be productive, thus contribute to economic growth.

Hence, a VAR model was fitted, in its panel form. More specifically, the model was adapted from Zouabi (2012), Hossain (2011), and Collard & Fève (2008). The PVAR has the advantage of encompassing the variation of the parameters of the model (system of equations) over time, and thus makes it possible to better restore the dynamics of the system, which gives credibility to the economic forecasts which adjust and adapt to the variations or shocks in the socio-economic environment.

The implicit endogeneity of the corresponding Vector autoregressive process of order p, VAR(p), especially on panel data, was specified as follows:

$$Y_{it} = \theta_i + \sum_{j=1}^{p} \Phi_{ij} Y_{it-j} + \omega_i X_{it} + \varepsilon_{it} \tag{1}$$

where *i* = 1, …, *N* countries and *t* = 1, …, *T* years. $Y_{it} = (Y_{1t}, \ldots, Y_{kt})$ is the vector of endogenous variables.

The considered structure comprising 4 dependent variables, over « *p* » optimal lags, is specified as follows:

$$\begin{cases} Urban_{it} = \alpha_0 + \sum_{j=1}^{p} \alpha_{1ij} Urban_{it-j} + \sum_{j=1}^{p} \alpha_{2ij} Clim_{it-j} + \sum_{j=1}^{p} \alpha_{3ij} gdp_{it-j} + \sum_{j=1}^{p} \alpha_{4ij} prod_{it-j} + \varepsilon_{1it} & (2) \\ Clim_{it} = \lambda_0 + \sum_{j=1}^{p} \lambda_{1ij} Clim_{it-j} + \sum_{j=1}^{p} \lambda_{2ij} Urban_{it-j} + \sum_{j=1}^{p} \lambda_{3ij} gdp_{it-j} + \sum_{j=1}^{p} \lambda_{4ij} prod_{it-j} + \varepsilon_{2it} & (3) \\ gdp_{it} = \beta_0 + \sum_{j=1}^{p} \beta_{1ij} gdp_{it-j} + \sum_{j=1}^{p} \beta_{2ij} Clim_{it-j} + \sum_{j=1}^{p} \beta_{3ij} Urban_{it-j} + \sum_{j=1}^{p} \beta_{4ij} prod_{it-j} + \varepsilon_{3it} & (4) \\ prod_{it} = \theta_0 + \sum_{j=1}^{p} \theta_{1ij} prod_{it-j} + \sum_{j=1}^{p} \theta_{2ij} Clim_{it-j} + \sum_{j=1}^{p} \theta_{3ij} Urban_{it-j} + \sum_{j=1}^{p} \theta_{4ij} gdp_{it-j} + \varepsilon_{4it} & (5) \end{cases}$$

Where $Urban_{it}$ defines the rate of urbanization of the country *i* at the time *t* and $Urban_{it-j}$ the lagged variable of the urbanization rate at the order *p*; $Clim_{it}$ is the variable measuring climate change (captured by the variability of either temperature or rainfall in each country *i* at the time *t* and $Clim_{it-j}$ the lagged value associated with climate change at the order *p* ; gdp_{it} is the rate of economic growth of country *i* at the time *t* and gdp_{it-j} the lagged of the rate of economic growth at the order *p*.

Variables specification and data

Urbanization is captured by the rate of urban population growth. Unlike the expression as a percentage of total population (Nguyen and Nguyen, 2018), the growth rate conveys a better understanding of the level of variation experienced by urbanization in sub-Saharan Africa from one period to the next.

Climate change commonly refers to significant changes in global temperature, precipitation, wind patterns and other measures of climate that occur over several decades or longer. Along those lines, the analysis of the effects of climate change on the economies of African countries appeared a bit too ambitious due to the long-term effect that it implies. Thus, logical preference was given to the concept of climate variability, as captured by the variations of either precipitation or temperature, thus highlighting climate anomalies in the climate literature (Nicholson, 1992; Munoz-Diazand, 2004). Following Marchiori et al, (2011), those anomalies were expressed as weighted deviations of the observed values from their long term mean in each of the considered countries. Hence, for the period 1968 – 2018, climate variabilities were determined as:

$$\Delta Clim_{i,t} = \frac{Clim_{i,t} - mean(Clim^{**}_{i,t})}{\sigma(Clim^{**}_{i,t})} \quad (6)$$

where, $\Delta Clim_{i,t}$ represents the climate anomaly of temperature or precipitation of country *i* at time *t* ; $mean(Clim^{**}_{i,t})$ is the climatic mean in country *i* at time *t* over the longer run ; $\sigma(Clim^{**}_{i,t})$ is the standard deviation of the observation over the long run, for country *i* at time *t*; $Clim_{i,t}$ is the observed climatic variable of country *i* at time *t*.

Economic growth is captured by the rate of economic growth. It measures the variability of wealth created by economic agents from one period to the other. For a considered country, an improvement in the rate is synonymous of the productive dynamics of the country's economic system (Hossain, 2011; Nassori, 2017).

Agricultural productivity is measured by the ratio of total gross production (total output) to the total input (all the factors of production used, including land; Livestock capital; Machine capital; fertilizers, etc.). There appeared a need to include an agricultural variable given the strong dependence of the considered economies on agriculture. Indeed, in most cases, a declining agricultural productivity leads populations to invade forests, grasslands and swamplands that can influence rainfall variability, hence increasing the level of poverty and the likelihood of migration (UN, 2002). This is further corroborated by authors such as Lewis (1954), Harris and Todaro (1970), who pointed out that an increase in agricultural productivity leads to a surplus of labor that will migrate from rural to urban areas to constitute a labor force for the industrial sector. More specifically, the rate of growth in agricultural productivity is considered.

Data sources. The data are those on a sample of sub-Saharan African countries: 14 out of the 16 West African countries; 10 over the 18 countries in East Africa; four countries out of nine in Central Africa and four out of the five southern African counties, as shown in table A1 of the Appendix. The variables and their sources are defined in Table 8.

Table 8: Specification of the Variables

Variables	Description of variables	Sources
	Dependent Variables	
Urban	Growth rate of urban population (%)	WDI (World Development Indicators, World Bank)
Vtemp50	Variation in temperature (°C)	CEDA (Center of Environnemental Documentation and Analysis)
gdp	Economic growth (%)	WDI
Prod	Agricultural productivity (%)	USDA (United State Department of Agriculture)

Source: Adapted from Kamgnia and Djezou (2021)

Evidence of the interactions between urbanization and climate variability

The descriptive statistics of the considered variables are first presented, followed by the discussion of the findings.

Descriptive characteristics of the variables

Table 9 presents the descriptive characteristics of the considered variables. Urbanization showed the smallest variability among the considered Sub-Saharan African economies; with an average increase of 3.88% per year. With an average of 3.80%, the economic growth rate of the considered economies was highly dispersed from a minimum of -50.25%, to a maximum of 35.22% over the considered period. Similarly, rainfall variability is widely dispersed from country to country with an average of 0.017 versus a higher variability in temperature, at a level of 0.91, and a mean of 0.55, indicating the presence of high heat variability among the considered countries. Appendix table2 presents the years in which and countries where the minimum or the maximum of each one of the considered variables was observed. For instance, the maximum value of 35.22% for economic growth was observed in Rwanda in 1995, whereas the highest inflation rate of 159.267% was observed in Sudan in 1994, as reported by Kamgnia and Djezou (2021).

Table 9: Descriptive characteristics of the variables

Variables	Observations	Mean	Stand Deviation	Minimum	Maximum
gdp	928	3.7992	5.0174	-50.24807	35.2241
Urban	928	3.8773	1.6882	-1.4768	17.4991
Prod	928	0.0056	0.0782	-0.4585	0.5420
Vtemp50	928	0.5470	0.7116	-1.4523	2.4729

Source: Adapted from Kamgnia and Djezou (2021)

Time series characteristics of the variables

First, the structure of the panel was tested for its existence. Specifically, a Fisher homogeneity test was run to determine whether the data generation process is homogeneous or heterogeneous. The results in Appendix table 3 indicate that the panel structure is heterogeneous at the 1% significance level; what confirms the structure of the considered panel.

As concerns the time series characteristics of the variables, some first-generation tests (LLC; ADF; IPS), and second-generation stationarity tests (CADF; CIPS) were performed. The results of these tests indicate a rejection of the null hypothesis of individual independence (see Appendix Table A4).

Specifically, the results of the CADF (Covariate Augmented Dickey-Fuller) and CIPS (Covariate Im-Pesaran-Shin) unit root tests presented in table 3 indicate that all the variables of interest are integrated to the order 0. Hence, a PVAR was fitted, at an order one, as determined in table 4. The GMM fit was further tested for the stability of the PVAR. As shown in Appendix table A5, all the eigenvalues fall within the unit radius circle, hence confirming the stability of the estimated PVAR.

Table 10: Results of the Unit Roots tests

Variables	CADF Test				CIPS Test				
					10 % (-2.54); -- 5 % (-2.61); --1% (-2.73)				
	Level		First Différence		Level		First Différence		
	P-value	Deci-sion	P-value	Deci-sion	CIPS	Deci-sion	CIPS	Deci-sion	Final decision
gdp	0,000	I(0)	---	---	-4.818	I(0)	---	---	I(0)
Urban	0,000	I(0)	---	---	-2.929	I(0)	---	---	I(0)
Prod	0,000	I(0)	---	---	-5.818	I(0)	---	---	I(0)
Vtemp50	0,000	I(0)	---	---	-4.854	I(0)	---	---	I(0)

Note: Values in parentheses indicate the critical values at the indicated significance level for the CIPS test.
Source: Adapted from Kamgnia and Djezou (2021)

Table 11: Determination of the number of lags

Lag	MBIC	MAIC	MQIC
1	-123.0377*	2.3446	-45.9142*
2	-92.2944	-8.7060*	-40.8785
3	-42.7901	-0.9960	-17.0823

Note: Bayesian Information Criterion (MBIC); Akaike Criterion (MAIC); Hannan and Quinn Information Criterion (MQIC)
Source: Adapted from Kamgnia and Djezou (2021)

Granger causality analysis

The results of the Granger causality test for determining the interactions among the variables of interest are presented in Table 12.

Table 12: Granger causality test accounting for all the countries

Variables	gdp	Urban	Prod	Vtemp50
gdp	--------------	0.017	0.067	1.128
		(0.895)	(0.796)	(0.288)
Urban	3.159*	--------------	2.249	12.209***
	(0.076)		(0.134)	(0.000)
Prod	17.900***	10.297***	--------------	14.452***
	(0.000)	(0.001)		(0.000)
Vtemp50	0.711	2.937*	1.299	--------------
	(0.399)	(0.087)	(0.254)	

*Note: Variables along the lines Granger cause variables along the columns; values in parentheses indicate the p-values of the estimated coefficients; hence ***, ** and * represent significance level at 1%, 5%, and 10% respectively.*
Source: Adapted from Kamgnia and Djezou (2020)

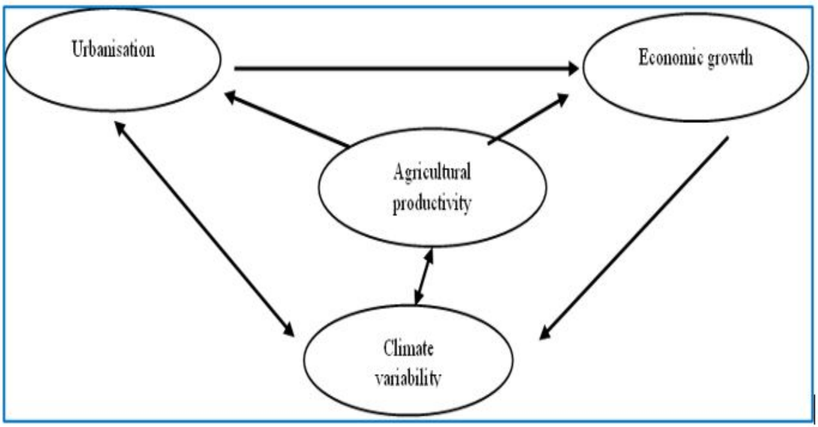
Table 13: Estimated coefficients of the PVAR model accounting for all the countries

Variables	gdp	Urban	Prod	Vtemp50
gdp	--------------	0.0009	-0.0001	0.0057
		(0.895)	(0.796)	(0.288)
Urban	- 0.6740*	--------------	-0.0078	-0.1623***
	(0.076)		(0.134)	(0.000)
Prod	-11.0146***	2.4450***	--------------	-2.0169***
	(0.000)	(0.001)		(0.000)
Vtemp50	-0.2769	0.9926*	-0.0063	--------------
	(0.399)	(0.067)	(0.254)	

*Note: values in parentheses indicate the p-values of the estimated coefficients; hence ***, ** and * represent significance level at 1%, 5%, and 10% respectively.*
Source: Adapted from Kamgnia and Djezou (2020).

Agricultural productivity Granger causes economic growth (-), urbanization (+), and climate variability (-), whereas urbanization causes economic growth (-), as well as climate variability (-). In return, climate variability Granger causes urbanization (+). Specifically, the findings confirm a bi-dimensional causality between climate variability and urbanization, indicating that worsened climate variability will contribute negatively to predict urbanization whereas increasing urbanization contributes positively to the prediction of climate variability, as expected, and discussed so far. The directions of the causalities for all the considered countries are defined in table 6. And represented in Figure 16.

Figure 16: Empirical interactions among climate change, urbanization, and economic growth accounting for all the countries



Source: Adapted from Kamgnia and Djezou (2020)

Findings on Sahelian countries sustain negative bidimensional causalities between agricultural productivity and economic growth, agricultural productivity, and urbanization, as well as between climate variability and urbanization (Table A6 and A7 in the Appendix). The economic justification of the observed interactions is discussed in the next sub-section.

Economic justification of the interactions between urbanization and climate variability

The current empirical evidence supports the existence of bi-dimensional causality between climate variability and urbanization, in the face of the interactions between agricultural productivity and economic growth. As revealed by the impulse reaction functions (Appendix table A8), a one standard error shock on urbanization slightly decreases the variability in temperature in the first year, followed by a steady increase in the years after. But a one standard error shock in the variability of the temperature sharply increases urbanization in the first year, followed by a moderate increasing effect, thereafter, in support of the rural-urban migration induced by climate variability.

In line with the economic theory, the results highlight the positive one-way causal effect of agricultural productivity towards urbanization. This effect grows faster in the first year, then starts declining in the second year before it stabilizes in the long run, around zero, as revealed by the impulse response functions (Appendix table A8). This observation is explained by the peculiarity of the agricultural production factors in sub-Saharan Africa, which are mainly labor, land and livestock capital. Thus, an increase in agricultural productivity will encourage mainly agricultural rural populations to migrate in urban areas. Such an assertion is justified by the average level of agricultural productivity in the sub-Saharan Africa, which revealed an upward trend in most of the considered countries. This result is in line with Lewis (1954), as well as with Fei and Ranis (1961) who examined the mechanisms for transferring the surplus labor from the traditional sector to a modern capitalist sector with unlimited labor. Of course, that does not mean that the agricultural sector in sub-Saharan Africa has reached full employment. Rather, an increased agricultural productivity tends to create an additional workforce that will be used primarily by the industrial and urban service sectors.

Indeed, the analysis of the impulse response functions reveals that urbanization negatively affects economic growth in Sub-Saharan Africa (Appendix table A8). A one standard deviation chock on urbanization leads to a decrease in economic growth in the first year, to then start improving in the following years, yet without becoming positive. Such results are contrary to the findings of Remy & Nols (1972), Davis & Henderson (2003), Cali (2008), and Lewis (2014) of a positive effect, as shown in the literature review.

However, the negative relationship between economic growth and urbanization in sub-Saharan Africa could be due the structure of urban areas, as pointed out by Frick and Pose (2018). To these authors, economic growth of this region is not sufficiently accompanied by the construction of adequate infrastructure to meet the needs of urban populations (Henderson et al, 2016; Kessides and Christine, 2007; Dorosh and Thurlow, 2012a). Indeed, considering only landlocked countries with low industrial value added, especially those of the Sahel region, the relationship between urban growth and economic growth becomes positive. It could be that for those countries, migration to urban areas meets a specific need for labor force; in support of Lewis' theory of rural-urban migration (1954). As concerns chocks on agricultural productivity, the effects were the most significant for the Sahel countries. A one standard deviation chock on agricultural productivity sharply increases climatic variability in the first year, and then starts decreasing slowly over the years, for the Sahel countries. In the other countries, urbanization increases temperature in the first year. Economic growth recovers from its fall in the second year to show a positive trend in the longer run.

Coping with interlinkages between Urbanization and Climate Change Vulnerability: mitigation and adaptation strategies

As pointed out by Mpandeli et al. (2020), and further highlighted by the above discussion, "climatic and environmental changes, coupled with population changes and migration, and their intricate relationships with development, are among the most pressing challenges dominating global sustainability discourses". Of course, UNEP (2007) indicates that Africa emerged as the most vulnerable region due to its technological, managerial, administrative, and financial unpreparedness. But several mitigation and adaptation strategies could be mobilized by African countries to cope with interlinkages between Urbanization and Climate Change Vulnerability.

One would recall that mitigation is an intervention to reduce sources or increased sinks of greenhouse gases, among others. Adaptation rather is "an adjustment of natural or human systems in response to present or future climate stimuli or their effects, in order to mitigate adverse effects or exploit beneficial opportunities" (IPCC 2001). While the two terminologies have similarities and may be complementary to each other, it would be emphasized that mitigation has a long-term effect due to the inertia of the climate system, while adaptation may have a short-term effect on reducing vulnerability. Given that the economies of several countries are highly dependent on agriculture, actions to ensure crop resilience have been adopted. Also, energy transition has been recommended and experienced with success in some countries. Adaptation strategies to cope with urbanization-induced vulnerabilities have been adopted. These strategies include investment in agricultural science and technology research; mobilization of municipal authorities on the prevention of climatic risks; promotion of the best available technologies for stormwater management; protection and reintroduction of nature in cities, in the forms of development of green spaces and greening to improve thermal comfort, thus increase the acceptability of densification and protect biodiversity.

However, two mitigation and adaptation schemes, namely urban development sustainability nexus, and migration planning nexus, are prioritized to nurture the current discussion among researchers and decision makers.

Urban development sustainability nexus

Urbanization is central to global environmental change and as such would necessarily be integral to a transition towards sustainability (Satterthwaite, 2014). Pieces of information to mobilize for ensuring the transition are, among others, the facts that urban vulnerabilities are manifested in areas of water resources, health, housing, energy, food security, functional transport infrastructure, environmental services, and economic productivity (IPCC, 2007). These points are well shared by many authors, including Childers et al. (2015), Pickett et al. (2016), Lwasa (2010), the World Bank (2011), and Satterthwaite (2008).

Pickett et al. (2016) advocate the development of urban ecological science, reconciling concerns for ecology in, ecology of, and ecology for the cities. Specifically, ecology in the city synthetizes the views of biologically oriented ecologists who "take their toolkit into cities, suburbs, and towns to study habitat or ecosystem types that are familiar to them, but which are embedded in an urban or urbanizing matrix". Ecology of the city moves beyond the ecology in the city, concentrating on rigorous characterization of patches and habitats that are not dominated by non-human organisms, and on understanding of how the social and socially determined human processes affect and pervade even the analog patches that ecologists had been studying traditionally. Ecology for the city is a blend of the ecology in and ecology for, yet in engaging scientists and scientific knowledge in dialog and practice for action toward the envisioned sustainable city. Despites their conceptual and methodological differences, the three approaches agree that the interactions between social and bio geophysical structures and processes are pervasive, reciprocal, and intertwined, thus should be mobilized in the quest for sustainable cities and a better future.

Along those lines, Childers et al. (2015) contend that "because green and blue infrastructure features take advantage of natural structures and ecological processes, they are surprisingly adaptable to a changing future, and thus impart resilience to urban systems far more than do inertia-bound gray infrastructures". One of the numerous options for using green and/or blue infrastructure designs, instead of gray infrastructure, is to ensure that representatives of all disciplines and perspectives participate in the design process, from beginning to end. "Green" infrastructure incorporates gardens, parks, street trees, community gardens, including multipurpose and multi-function stormwater management facilities. "Blue" infrastructure, however, is built on variety of water features that provide a range of ecosystem services, including rivers and streams, lakes, and fountains. To advance climate change resilience and enhance future sustainability, cities of all forms should benefit from the transformative nexus of ecology and design proposed by these authors.

Of course, Lwasa (2010) concurs to the adaption through spatial planning, energy efficient housing and transportation, conservation of urban natural resources, urban greening, local economic development, and integration of the "emerging" informal sector into the urban economy and planning for low-carbon economies; all these taking into account "green" technologies with a potential to reduce poverty. But this author further voices that these points constitute the most critical areas for future research in Africa, including urban governance and preparedness for climate change.

Indeed, the central role in adaptation to climate change is to be played by urban governments, within their various jurisdictions. The World Bank (2011) specifically points to responsibilities related to the delivery of a wide range of services that ensure the well-being of their citizens. Such services include, among others, land use planning and zoning; water provision, sanitation, and drainage; housing construction, renovation, and regulation; economic development; public health and emergency management; transportation provision, and environmental protection. As further stated by Satterthwaite (2008), private companies or nonprofit institutions may provide some of the key services. But the interventions of the private sector are to be done in partnership with local government or local offices or national or provincial government, for quality control and effectiveness. Key supportive institutional, regulatory, and financial framework from higher levels of government and, exceptionally from international agencies for most low- and middle-income nations, should ease the interventions of urban governments.

Migration, an adaptation strategy to climate vulnerability

An ongoing premise is that migration can become an adaptation strategy (not necessarily a challenge) if the receiving area has the resources and is prepared to absorb a high influx of migrants without shacking its systems (Mpandeli et al., 2020). The thrust of this premise rests on the "planning" of the phenomenon. The lines below highlight the specificity of nexus planning migration, as a response to climate induced migration.

Evidence of climate induced migration

Of course, some of the migration to cities is due to the desire of the rural population to enjoy the benefits that urban areas offer. Urban benefits include greater opportunities to receive education, health care and services; or simply in search for employment opportunities, as reported by Marchetta et al. (2021) in the case of Madagascar, and Mbaye et al. (2021) for the continent.

Nonetheless, Mbaye et al. (2021) pointed out that migration has been cited by 23% of households as a coping strategy against climate change in a study on Sub-Saharan Africa. In effect, Rigaud et al. (2018) assert that one of the mechanisms for dealing with the loss of livelihoods due to climate change is migration out of affected areas. Some of this type of migration can take place in other countries. But much of it is expected to be internal, e.g., in urban areas, or areas less affected by climate change, where migration costs are lower and challenges are less daunting (Mastrorillo et al., 2016; Dallmann and Millock, 2017).

This point is highly shared by Marchetta et al. (2021) in the conceptualization of their study. The authors specifically estimated the migration response to climate shocks in Madagascar among cohort members, who are in the transition between adolescence and young adulthood between 2004 and 2011. Although they found a strong negative impact of drought on the decision of youth to migrate in the year after the adverse weather shock, the authors contend that liquidity constraints that occur after income shocks rather prevented youth migration in rural Madagascar as a response to climate variability.

Chegere and Mrosso (2021) specially analyzed migration as an adaptation strategy to climate variability. They examined the decision and extent to which households engage in internal migration to shield themselves against agricultural risk due to climate-related shocks and how this affects the welfare of the households. Yet, their empirical analysis did not allow them to confirm migration as a response factor.

In all those cases of general migration, uncontrolled urban population growth due to climate variability can lead to unexpected effects on the environment and on the level of precariousness of populations.

Nexus planning migration into a mitigation and adaptation strategy

Mpandeli et al. (2020) developed a migration conceptual framework based on the nexus between water, food, and socio-economic interlinkages in the case of Southern Africa, to inform adaptation planning on permissible migration that are aligned with regional goals such as regional integration, poverty reduction and improved livelihoods. More generally, the design of a nexus framework is based on the analysis of the interaction among key sustainability indicators, such as water availability, water productivity, energy productivity, food crop productivity, food self-sufficiency, to determine the "poorly managed resource base, which leads to unsustainable development, thus triggers migration. In the specific case of South Africa, food-sufficiency led the construction, having been identified as the concern of the highest priority. But the region needs to equally develop other sectors, achieve a circular shape to best create an environment for planned migration.

The contention of these authors is that migration becomes an adaptation strategy only when it is planned, and people move from a high-risk place to a location where they are more secure from negative impacts. The thrust of that contention is to manage climate-induced migration and gain mutual benefits in both receiving and sending areas. The strategy focus on thematic areas of vulnerability, mitigation, preparedness, response and recovery. Overall, Mpendeli et al. (2020) conceived nexus planning for climate-induced migration as a win–win strategy which allows for climate action, including mitigation and adaptation, and the solving of numerous socio-economic challenges that southern Africa is currently facing.

In short, the conceived migration nexus should be viewed as a decision support framework that provides evidence-based intervention strategies to transform migration into a mitigation and adaptation strategy.

Conclusion

As reported in reviewed AERC studies, increasing urbanization coupled with climate change drive several risks and impacts, including droughts, cyclones, desertification, wildfires. The consequences are numerous, covering degradation of fisheries and loss of biodiversity, agriculture seasonal changes, depletion of water resources and limited ecosystem services, among others. Derived socio-economic changes include severe impacts on vulnerable communities, major cities, and densely populated regions, such as sea-level rise and other hazards, without omitting their impacts on migration and conflicts in Africa. Empirical evidence of the interlinkages between urbanization and climate variability supports the existence of a bi-dimensional causality between climate variability and urbanization. Climate variability contributes negatively to predictions in urbanization whereas increasing urbanization contributes positively to predictions in climate variability. Moreover, being a Sahelian country sustains negative bidimensional causalities between agricultural productivity and economic growth, between agricultural productivity and urbanization, as well as between climate variability and urbanization.

As a response to the question "What Next?", two mitigation and adaptation schemes for coping with the interlinkages between urbanization and climate change vulnerability in Sub-Sharan Africa, namely urban development sustainability nexus, and nexus planning migration, were prioritized to nurture the discussion in the AERC XXIV SPS among researchers and decision makers. Urban development sustainability nexus features green and blue infrastructures to mobilize their natural structures and ecological processes, hence ensure resilience to urban systems. Nexus planning migration, rather, is meant to manage climate-induced migration and gain mutual benefits in both receiving and sending areas, as a means for mitigating and adapting to the interactions between urbanization and climate change vulnerability.

Then to what extend urban development sustainability nexus on the one hand, and nexus planning migration on the other hand, can be mobilized as viable strategies to cope with interlinkages between increasing urbanization and climate change vulnerability in Sub-Saharan Africa? Responses call for some recommendations, of which the following:

To Researchers:

- Provide more information on urbanization and climate change vulnerability.
- Identify appropriate methodological approaches for understanding the thrust of the suggested strategies; and inform on potential policy responses.

To Governments:

- Engage in urban planning, prioritizing green and blue infrastructure features.
- Exploit the benefit of nexus planning migration.

  Enforce stronger management policies to improve good governance.
- Convene adaptation partnership among cities, county, regional, state, and federal entities.
- Promote PPP in urban development.

To Think Tanks and to the AERC:

- Provide platforms for knowledge generation and for better understanding of climate change vulnerability adaptation.
- Engage further in information sharing among researchers and between researchers and stakeholders on issues of adaptation to urbanization and climate change vulnerability.

To Development partners:

- Provide funding for research projects for understanding urbanization dynamics and climatic vulnerability.
- Offer strategic advice and technical assistance to cities on mitigation and adaptation.

References

Alberti, M. (2008). Atmospheric Processes. *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems*, 183–196. doi.org/10.1007/978-0-387-75510-6_4.

Bai, X., McPhearson, T., Cleugh, H., Nagendra, H., Tong, X., Zhu, T., & Zhu, Y. G. (2017). "Linking urbanization and the environment: Conceptual and empirical advances". *Annual Review of Environment and Resources,* 42, 215–240. doi.org/10.1146/annurev-environ-102016-061128.

Barbier, E. B., & Hochard, J. P. (2018). "Poverty, rural population distribution and climate change". *Environment and Development Economics*, 23(3), 234–256. doi.org/10.1017/S1355770X17000353.

Cattaneo, C., & Peri, G. (2016). "The migration response to increasing temperatures". *Journal of Development Economics*, 122, 127–146.

Chegere J. M., & Mrosso L. Th. (2021), Climate variability, internal migration and household welfare among agricultural households in Tanzania.

Childers, D. L., Cadenasso, M. L., Morgan Grove, J., Marshall, V., McGrath, B., and Pickett, T. A. (2015). An Ecology for Cities: A Transformational Nexus of Design and Ecology to Advance Climate Change Resilience and Urban Sustainability, Sustainability, 7, 3774-3791; doi:10.3390/su7043774. doi:10.3390/su7043774.

Dallmann, I., & Millock, K. (2017). Climate variability and inter-state migration in India. *CESifo Economic Studies*, 63(4), 560-594. doi.org/10.1093/cesifo/ifx014.

Devlin, C., & Hendrix, C. S. (2014). "Trends and triggers redux: climate change, rainfall, and interstate conflict". *Political Geography,* 43, 27–39. doi.org/10.1016/j.polgeo.2014.07.001.

Dorosh, P., & Thurlow, J. (2012). "Agglomeration, growth, and regional equity: an analysis of agriculture-versus urban-led development in Uganda". *Journal of African Economies,* 21(1), 94-123. doi.org/10.1177/0956247813490908.

Ebeke, C., & Mireille, N. E. (2021). Climate Instability and Agricultural Productivity in Africa: Cross-Country Evidence.

Frick, S. A., & Rodríguez-Pose, A. (2018). "Change in urban concentration and economic growth". *World Development*, 105, 156–170. doi: 10.1016/j.worlddev.2017.12.034.

Garschagen, M., & Romero-Lankao, P. (2015). "Exploring the relationships between urbanization trends and climate change vulnerability". *Climatic Change*, 133(1), 37–52. doi: 10.1007/s10584-013-0812-6.

Gaston, K. J., Davies, Z. G., & Edmondson, J. L. (2010). "Urban environments and ecosystem functions". *Urban Ecology,* 35–52. doi : 10.1111/j.1749-6632.2010.05925.x.

Grimm, N., Faeth, S. H., Golubiewski, E. N., Redman, L. Ch., Wu, J., Bai, X., and Briggs, M. J. (2008). Global Change and the Ecology of Cities, *Science* 319, 756, DOI: 10.1126/science.1150195. doi: 10.1126/science.1150195.

Harris, J. R., & Todaro, M. P. (1970). "Migration, Unemployment, and Development: A Two-sector analysis". *The American Economic Review*, 60(1), 126–142. doi : 10.4236/me.2011.22023.

Henderson, J. V., Storeygard, A., & Deichmann, U. (2017). Has climate change driven urbanization in Africa?. *Journal of development economics, 124,* 60–82. doi: 10.1016/j.jdeveco.2016.09.001.

Hirsch, Y. (2017). Caractéristiques de l'îlot de chaleur urbain et recherche d'une solution paysagère pour le site de la résidence Damrémont à Paris. http://hdl.handle.net/2268.2/2982.

Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., & Peisker, J. (2020). A meta-analysis of country-level studies on environmental change and migration. *Nature Climate Change,* 10(10), 904–912. doi.org/10.1038/s41558-020-0898-6.

Hossain, M. S. (2011). Panel estimation for CO2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy*, 39(11), 6991–6999. doi: 10.1016/j.enpol.2011.07.042.

IPCC. 2014. "Climate change 2014: Impacts, adaptation, and vulnerability". Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Edited by Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea, M.D., Bilir, T.E., Chattzejee, M., Ebi K.L., Estrada Y.O., Genova R.C., Girma, B., Kissel, E.S., Levy A.N., Maccracken, S., Mastrandrea, P.R. and White, L.L. Cambridge: Cambridge University Press.

IPCC (2007). Climate Change 2007: Synthesis Report, L. Bernstein, et al., eds., 2007, Intergovernmental Panel on Climate Change: Valencia.

Kamgnia, B. D., & Djezou, W. B. (2021). Climate Variability and Urbanization in Sub-Saharan Africa: Mitigating the Effects on Economic Growth. Working-Paper-Series-CC-010.

Kamgnia, B. D., & Djezou, W. B. (2020). Climate Variability and Urbanization in Sub-Saharan Africa: Mitigating the Effects on Economic Growth. Work in Progress.

Kessides, C. (2007). "The urban transition in Sub-Saharan Africa: challenges and opportunities". *Environment and Planning C: Government and Policy, 25*(4), 466–485. doi.org/10.1068/c3p.

Kohler, T., Wehrli, A. & Jurek, M., eds. 2014. Mountains and climate change: A global concern. Sustainable Mountain Development Series. Bern, Switzerland, Centre for Development and Environment (CDE), Swiss Agency for Development and Cooperation (SDC) and Geographica Bernensia. 136 pp.

Lewis, W. A. (1954). Economic development with unlimited supplies of labour. The Manchester School. doi.org/10.1111/j.1467-9957. 1954.tb00021.x.

Lwasa, S., & Kadilo, G. (2010). Participatory action research, strengthening institutional capacity and governance: Confronting the urban challenge in Kampala. *Commonwealth Journal of Local Governance*, (5), 27–46. doi: 10.5130/CJLG.V015.1467.

Lwasa S. (2010). Urban Vulnerabilities and Adaptation in Low Income Countries;
Perspectives for Future Research in Africa, in UGEC Viewpoints | No. 4 | October 2010 | www.ugec.org.

Marchetta, F., Sahn, D. E., Tiberti, L., & Dufour, J. (2021). Heterogeneity in migration responses to climate shocks: evidence from Madagascar. *Available at SSRN 3771735*.

Marchiori, L., & Schumacher, I. (2011). When nature rebels: international migration, climate change, and inequality. *Journal of Population Economics*, 24(2), 569–600. doi: 10.1007/s00148-009-0274-3.

Marchiori, L., Maystadt, J. F., & Schumacher, I. (2012). The impact of weather anomalies on migration in sub-Saharan Africa. *Journal of Environmental Economics and Management,* 63(3), 355-374. doi: 10.1016/j.jeem.2012.02.001.

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, L. D., & Oppenheimer, M. (2016). The influence of climate variability on internal migration flows in South Africa. *Global Environmental Change*, 39, 155–169. doi.org/10.1016/j.gloenvcha.2016.04.014.

Mayaki, I. A., Bossard, L., & Pezzini, M. (2017). Where cities can take Africa. *Organisation for Economic Cooperation and Development. The OECD Observer,* 1F. doi.org/10.1787/15615529.

Mbaye, A. A., Gueye, A., Gueye F., & Sarr, Y. K. (2021), Climate Change and Migration in West African Coastal Zones, AERC Working Paper Series: CC-008, African Economic Research Consortium, Nairobi, September.

Mortoja, M., & Yigitcanlar, T. (2020). How does peri-urbanization trigger climate change vulnerabilities? An investigation of the dhaka megacity in Bangladesh. *Remote Sensing*, 12(23), 3938. oi.org/10.3390/rs12233938 oi.org/10.3390/rs12233938.

Mpandeli, S., Nhamo, L., Hlahla, S., Naidoo, D., Liphadzi, S., Modi, T. A., Mabhaudhi, T. (2020). Migration under Climate Change in Southern Africa: A Nexus Planning Perspective, Sustainability 2020, 12, 4722; doi:10.3390/su12114722.

Munoz-Diaz, D., & Rodrigo, F. S. (2004). Spatio-temporal patterns of seasonal rainfall in Spain (1912-2000) using cluster and principal component analysis: comparison. In *Annales Geophysicae*, 22(5), 1435–1448. SRef-ID: 1432-0576/ag/2004-22-1435.

Nicholson, S. E. (1993). An overview of African rainfall fluctuations of the last decade. *Journal of climate,* 1463-1466. doi.org/10.1175/1520-0442(1993)006<1463:AOOARF>2.0.CO;2.

OCHA. (2020). West and Central Africa: Flooding Situation Overview, https://reliefweb.int/report/niger/west-and-central-africa-flooding-situation-overview-january-december-2020-18-december.

OCHA (2020). Eastern Africa Region: Floods and Locust Outbreak Snapshot, 11 May, https://reliefweb.int/report/ethiopia/eastern-africa-region-floods-and-locust-outbreak-snapshot-may-2020.

Ouédraogo M. (2021). Extreme climate events and conflicts: The case of G5-Sahel countries. Preliminary draft, Extract from AERC funded study, with the support of the Norwegian Agency for Development Cooperation (Norad) collaborative research project on Climate Change and Economic Development in Africa (CCEDA.

Pickett, T.S., Cadenasso, L.M., Childers, L. D., McDonnell, J. M., and Zhou, W. (2016). "Evolution and future of urban ecological science: ecology in, of, and for the city". *Ecosystem Health and Sustainability* 2(7): e01229. doi:10.1002/ehs2.1229.

Ranis, G., & Fei, J. C. (1961). "A theory of economic development". *The American Economic Review,* 533-565. doi: 10.4236/aasoci.2016.611028.

Rigaud, K. K., Heuser, S., Abu-Ata, N., & Arora, A. (2021). Operational Experiences and Lessons Learned at the Climate Migration Development Nexus. P76. P170862081666c03309d56023c0e600e5c4.pdf?sequence=5.

Satterthwaite, D. (2014). Urban Areas from Climate Change 2014: Impacts, Adaptation, and Vulnerability. IPCC WGII AR5 Ch 8.

Satterthwaite, D. (2008). Climate change and urbanization: effects and implications for urban governance, United Nations Expert Group Meeting on population, urbanization, internal migration, and development, UN/POP/EGM-URB/2008/16.

Shahin, M., Ali, M., & Ali, A. B. M. (2014). Vector Autoregression (VAR) modeling and forecasting of temperature, humidity, and cloud coverage. In, *Computational Intelligence Techniques in Earth and Environmental Sciences* (pp. 29–51). Springer, Dordrecht. doi: 10.1007/978-94-017-8642-3_2.

Snyder, H. (2019). "Literature review as a research methodology: An overview and guidelines", *Journal of Business Research* 104, pp333–339. doi.org/10.1016/j.jbusres.2019.07.039.

Todaro, M. P. (1969). A model of labor migration and urban unemployment in less developed countries. *The American economic review,* 59(1), 138-148. RePEc:aea:aecrev:v:59:y:1969:i:1:p:138–48.

UNHCR (2021). Rapport du Haut-Commissaire des Nations Unies pour les réfugiés, Nations Unies. New York. A/76/12.

Watkins, M.H. & Griffith, C.A. (Eds.). (2015). Synthesis Report from the 2nd International Conference on Urbanization and Global Environmental Change. Urban Transitions & Transformations: Science, Synthesis and Policy. Tempe, USA: Urbanization and Global Environmental Change Project.

World Bank (2011). Guide to Climate Change Adaptation in Cities. Product of the staff of the International Bank for Reconstruction and Development / The World Bank. Pp 106. https://openknowledge.worldbank.org/handle/10986/27396 License: CC BY 3.0 IGO.

Zouabi, O. (2012). Climate change, agriculture, and economic growth: A VAR modeling. Pp.1–19. https://EconPapers.repec.org/RePEc:pra:mprapa:61072.

Appendix

Table A1: List of countries in the Panel

Western Africa (13/14)
Benin - Burkina Faso - Côte d'Ivoire - Gambia - Ghana - Guinea Bissau - Mali - Mauritania - Niger - Nigeria - Senegal - Sierra Leone – Togo
Eastern Africa (10/17)
Burundi - Comoros - Mauritius - Kenya - Madagascar - Rwanda - Soudan - Tanzania – Uganda – Zimbabwe
Central Africa (04/8)
Cameroon - Congo république - Gabon - Chad
Southern Africa (04/9)
South Africa - Botswana - Namibia – Eswatini (Swaziland)

Source: Adapted from Kamgnia and Djezou (2020)

Table A2: Years and countries where the minimum or maximum was observed

Variables	**Minimum**			**Maximum**		
	Value	**Country where it was observed**	**Year**	**Value**	**Country where it was observed**	**Year**
gdp	-50.24807	Rwanda	1994	35.22408	Rwanda	1995
Urban	-1.4767	Rwanda	1991	17.4990	Rwanda	1996
Prod	-0.4585	Namibia	1997	0.5419	Botswana	1991
Vprec50	-3.3384	Rwanda	2004	4.0525	Swaziland	2000
Vtemp50	-1.452284	Soudan	1992	2.4728	Soudan	2010
Labor	42.22	Comoros	1990	91.542	Burundi	1990
Inv	-2.4243	Sierra Leone	1997	61.4690	Mauritanie	2005
Infl	-29.6910	Republic of Congo	2015	159.267	Soudan	1994
Vaind	2.0731	Soudan	2015	77.4136	République Congo	2008
Political	1	Botswana (1990-1992) ; Gambia (1992) ; Ghana (2005-2018) ; Mauritania (1993-2018) ; South Africa (1995-2005)		7	Almost all the countries achieved a maximum of 7 in a given year over the considered period.	

Source: Adapted from Kamgnia and Djezou (2020)

Table A3: Fisher homogeneity Test

Case 1 : rainfall variations

```
. testparm pib urban prod var_precip

 ( 1)  urban = 0
 ( 2)  prod = 0
 ( 3)  var_precip = 0

           chi2(  3) =   34.88
         Prob > chi2 =    0.0000
```

Case 2 : temperature variation

```
. testparm pib urban prod var_temp

 ( 1)  urban = 0
 ( 2)  prod = 0
 ( 3)  var_temp = 0

           chi2(  3) =   30.97
         Prob > chi2 =    0.0000
```

Table A4: Test of dependence of individuals

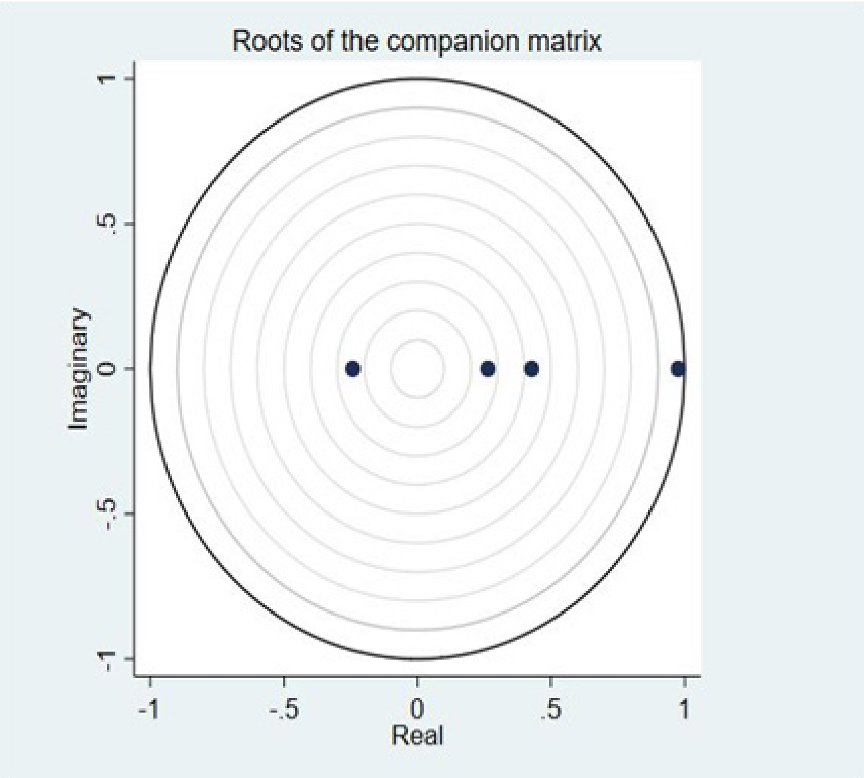
```
Average correlation coefficients & Pesaran (2004) CD test

Residual series tested: ols_res
                               Group variable: id
                             Number of groups: 32
                    Average # of observations: 29.94
                                     Panel is: unbalanced
```

Variable	CD-test	p-value	corr	abs(corr)
ols_res	10.27	0.000	0.086	0.178

```
Notes: Under the null hypothesis of cross-section
       independence CD ~ N(0,1)
```

Source: Adapted from Kamgnia and Djezou (2020)

Table A5: Stability test of the estimated PVAR



Source: Adapted from Kamgnia and Djezou (2020)

Table A6: Granger causality test for Sahelian countries

Variables	gdp	Urban	Prod	Vtemp50
gdp	--------------	3.844**	4.069**	0.517
		(0.050)	(0.044)	(0.472)
Urban	0.129	--------------	5.399**	3.798**
	(0.720)		(0.020)	(0.051)
Prod	34.415 ***	4.812**	--------------	6.275*
	(0.000)	(0.028)		(0.012)
Vtemp50	2.669*	7.026***	0.792	--------------
	(0.102)	(0.008)	(0.373)	

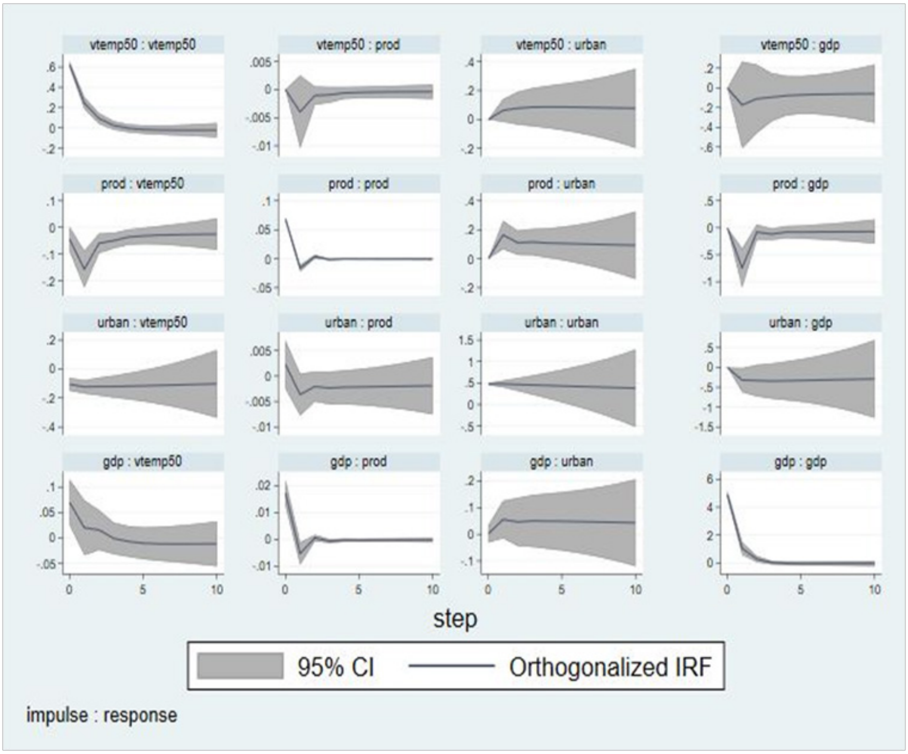
*Note: values in parentheses indicate the p-values of the estimated coefficients; hence ***, ** and * represent significance level at 1%, 5%, and 10% respectively.*
Source: Adapted from Kamgnia and Djezou (2020)

Table A7: Estimated coefficients of the PVAR model for Sahelian countries

Variables	gdp	Urban	Prod	Vtemp50
gdp	--------------	0,0075**	-0,0025**	0,0048
		(0.050)	(0.044)	(0.472)
Urban	-0,3932	--------------	-0,0371**	-0,2956**
	(0.720)		(0.020)	(0.051)
Prod	-21,5346***	-0,390**	--------------	-1,5120***
	(0.000)	(0.028)		(0.012)
Vtemp50	-0,5144*	-0,072***	-0,0076	--------------
	(0.102)	(0.008)	(0.373)	

*Note: values in parentheses indicate the p-values of the estimated coefficients; hence ***, ** and * represent significance level at 1%, 5%, and 10% respectively.*
Source: Adapted from Kamgnia and Djezou (2020)

Table A8: Impulse response functions with temperature variations



Source: Adapted from Kamgnia and Djezou (2020)

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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