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Climate change and income inequality in Sub-Saharan Africa (SSA): effects and transmission channels

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Abstract

Purpose – The purpose of this paper is to assess the direct effect of climate change on income inequality in Sub-Saharan Africa (SSA) and the channels through which it spreads.

Design/methodology/approach – Using a sample of 38 countries, the authors specify and estimate a panel data model using the generalized least squares method over the period 1991–2020. Robustness is achieved through the generalized moment method-system.

Findings – The results show that an increase in vulnerability to climate change is positively and significantly associated with an increase in income inequality. The results also show that the effects of climate change are mediated by gross domestic product/capita, population and agriculture at the 15%, 17% and 24% thresholds, respectively.

Research limitations/implications – The authors suggest the implementation of inclusive development policies consistent with climate mitigation and adaptation objectives; the creation of financial spaces from various sources to finance the social security of the most vulnerable; and the strengthening of agricultural resilience to climate-related adverse events, including financing for greenhouse agriculture.

Originality/value – On the positive side, it contributes to the literature on the analysis of the direct and indirect effects (transmission channels) of climate change on income inequality in SSA. Methodologically, the study goes beyond previous work as it adopts a stepwise methodology, dealing with the endogeneity issue. At the logical level, it offers some non-exhaustive suggestions of potentially interesting economic policies to guide policymakers in their common commitment to "reduce income inequality" (Sustainable Development Goal 10, target 10.1).

Keywords Income inequality, Sub-Saharan Africa, Climate change

Paper type Research paper

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1. Introduction

While Africa has experienced considerable growth since the early 2000s (an annual growth rate of 4.6%, according to the World Bank), this growth has not led to an improvement in well-being. Indeed, poverty and inequality remain the characteristics of the African social system. The continent is still marked by the deterioration of the quality of institutions, which hampers transaction costs, the protection of property rights, entrepreneurial activities and innovations (Saima, 2015). Although SSA saw a 3.4 percentage point decline in the unweighted average value of its Gini coefficient between 1991 and 2011, it remains one of the regions with the highest levels of inequality globally. Indeed, it is home to 10 of the 19 most unequal countries in the world (World Bank, 2003). In Sub-Saharan Africa, the average income is 31% of the world's income, while the richest 10% amass more than 56% of the wealth. Most highly unequal countries are in Southern Africa, although most of these economies are growing at some of the fastest rates in the world. Tanzania, for instance, despite robust economic growth (in the range of 6–7% per year), poverty declined by only 2.2 percentage points over the entire 1996–2010 period, well below the average annual reduction of 1.7 percentage points observed in Rwanda (World Bank Group, 2013). Considering the Gini coefficient as a measure used to assess the degree of income or wealth inequality within a specific society or group (Cevik and Jalles, 2023), studies have shown that Sub-Saharan Africa is also home to seven economies considered outliers in terms of Gini coefficients and therefore responsible for income inequality in the region (Xu *et al.*, 2021). With the coronavirus pandemic (COVID-19) and, since March 2022, the war between Russia and Ukraine, the African continent, which is already in the grip of a deleterious situation, is strongly affected. Indeed, this sequence of events has aggravated the already existing disparities between and within SSA countries (Bitoto and Ongo, 2024). The economic sanctions imposed by the European Union on Russia and their regional spread have caused commodity prices to fall and exports to decline in many SSA countries, resulting in lower household incomes and higher income inequality. Within this context, the issue of inequality is a universal appeal and is of great importance, as high levels of income inequality could weaken the effectiveness of development policies in terms of poverty reduction (Kaulihowa and Adjasi, 2018). Member states in the recent 2030 Sustainable Development Goals (SDGs) have committed to "reducing income inequality" (target 10.1). Thus, the field of study continues to attract the attention of economic researchers (Bourguignon and Morrisson, 1990; Stiglitz, 2012; Piketty, 2018; Piketty, 2015; Nkoa and Song, 2021). Exploring the key structural drivers of income inequality in SSA in 2021 reveals that these stem from the highly dualistic structure of the economy, with the driver of inequality resulting from the high concentration of physical capital, human capital and land often manifested through climate change (Chancel and Piketty, 2021).

While SSA remains the region that contributes the least to greenhouse gas (GHG) emissions, with less than 5% of the global total, it is perhaps the most vulnerable to climate shocks. Given the region's heavy reliance on rain-fed agriculture, SSA is particularly vulnerable to climate change, as one-third of the world's droughts occur in the region. Climate change also has multiplier effects on conflict and fragility, exacerbating pre-existing tensions, governance failures and socio-economic problems such as income inequality.

While considerable attention has been paid to analysing the effects of climate change on economic growth, the relationship between climate change and income inequality remains much less studied (Cevik and Jalles, 2022). This is particularly important given the increase in wealth and income inequality in most countries of the world over the past three decades, despite sustained economic growth and poverty reduction. In the future, climate change could undermine poverty eradication efforts, disproportionately affect the poorest regions and increase income inequality within countries.

Previous research on income inequality and emissions has found that national income inequality drives CO_2 emissions in high-income nations (Jorgenson *et al.*, 2016; Knight *et al.*, 2017; Ravallion *et al.*, 2000) and in the USA in particular (Jorgenson *et al.*, 2015, 2017). These analyses build on the stochastic impacts by population, affluence and technology regression (STIRPAT) tradition and, as such, estimate the effect of income inequality as an additional multiplicative contributor to environmental degradation. Overall, these studies conclude that the concentration of power coincides with the concentration of wealth, so that both contribute to the intensification of environmental degradation. Moreover, these studies remain limited in that they do not identify specific mechanisms that may link wealth inequality to emissions but merely demonstrate empirically an association between the two (Knight *et al.*, 2017). In this work, we broaden the scope of research studies by further identifying mechanisms that link inequality and climate change in particular.

This article therefore takes a fresh look at a little-studied area of the literature. Without being exhaustive, it makes three contributions. On the positive side, it contributes to the literature on the analysis of the direct and indirect effects (transmission channels) of climate change on income inequality in SSA. In all likelihood, the literature in SSA remains shy on the subject, although the region should be a privileged territory because it contributes the least to CO_2 emissions and suffers the most from the consequences. Methodologically, the study goes beyond previous work as it adopts a stepwise methodology. Moreover, to take advantage of the panel data, the dynamic model uses the generalized moment method-system (GMM-S), which corrects for the endogeneity of the explanatory variables of interest and the other explanatory variables. At the logical level, it offers some non-exhaustive suggestions of potentially interesting economic policies to guide policymakers in their common commitment to “reduce income inequality” (SDG 10, target 10.1).

The aim of this paper is to assess the direct effect of climate change on income inequality in SSA and the channels through which it is transmitted. Using a sample of 38 countries, we specify and estimate a panel data model using the generalized least squares (GLS) method over the period 1991–2020. Our results show that an increase in vulnerability to climate change is positively and significantly associated with an increase in income inequality. The results also show that the effects of climate change are transmitted through gross domestic product (GDP)/capita, population and agriculture. These results are robust to changing the estimation method to GMM-S and adding additional control variables. Three main recommendations emerge: the implementation of inclusive development policies consistent with climate mitigation and adaptation objectives; the creation of financial spaces from various sources (natural resource rents, tax revenues) to finance social security for the most vulnerable; and the strengthening of agricultural resilience to climate-related adverse events, including financing for greenhouse agriculture.

The remainder of the paper is organized into five additional sections. Section 2 illustrates some stylized facts, Section 3 presents the literature review, Section 4 outlines the different steps of the empirical strategy, Section 5 discusses the results and Section 6 concludes with policy suggestions.

2. Stylized facts

Three stylized facts emerge from the observation of climate change and income inequality in SSA et permettent une bonne imerssion dans la relation.

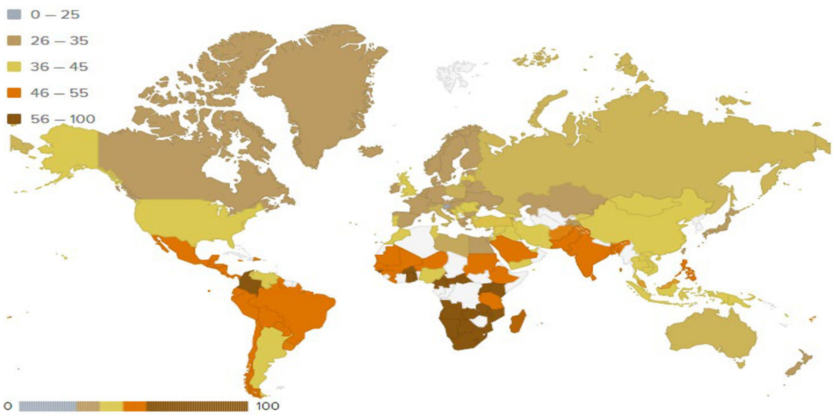
2.1 Income inequality persists in Sub-Saharan Africa

Figure 1 shows the map of income inequality in the world based on data from the World Income Inequality Database (2019). It can be seen that the African continent and SSA in particular is the region of the world where income inequality is most pronounced. As a result, South Africa is the country with the highest inequality. However, the country is far from being an exception on the continent. The literature informs us of several factors that are sources of inequality in countries and that we classify broadly into four orders: natural (Sebri and Dachraoui, 2021), economic (Piketty, 2015), political (Nkoa and Song, 2021) and competitiveness (Georgescu and Kinnunen, 2021).

Disparities of a natural order, because some regions are richer in natural resources (oil, mines, gas) than others, as in the case of Equatorial Guinea or Botswana, which have taken advantage of the abundance of natural resources to reduce poverty gaps in the country. Then there are economic disparities, as some regions perform better than others. Côte d'Ivoire, Mauritius and Rwanda, for example, achieved considerable economic performance over the last decade, in particular from 2014 to 2024, lifting millions of people out of extreme poverty, whereas other countries in the same sub-region are lagging behind. Another argument is that income inequality is linked to the social protection system because it redistributes income (Bhorat *et al.*, 2017). In terms of transfer value, SSA has the second-lowest amount of transfers per day per capita in the world at $0.51/day per capita (UNDP, 2017). Political disparities as highlighted in several studies, corruption (Khan, 2021), low levels of democracy and quality of institutions (Kemp-Benedict, 2011; Nkoa and Song, 2021). Finally, the disparities in competitiveness reflected in the fact that some regions and countries are more competitive, creative and innovative than others.

2.2 Sub-Saharan Africa is contributing the least to climate change but suffering the most from its consequences

Figure 2 highlights the reduced capacity of less developed countries in general, and sub-Saharan Africa in particular, to adapt to climate change. Developed countries and wealthier individuals contribute disproportionately to temperature increases through their level of consumption. There is a double disadvantage: those who contribute the least to climate change tend to suffer the most (Roberts, 2001; Althor *et al.*, 2016), and conversely, the most



Sources: UNU-WIDER (2019); author's treatment

Figure 1. Geography of global inequalities

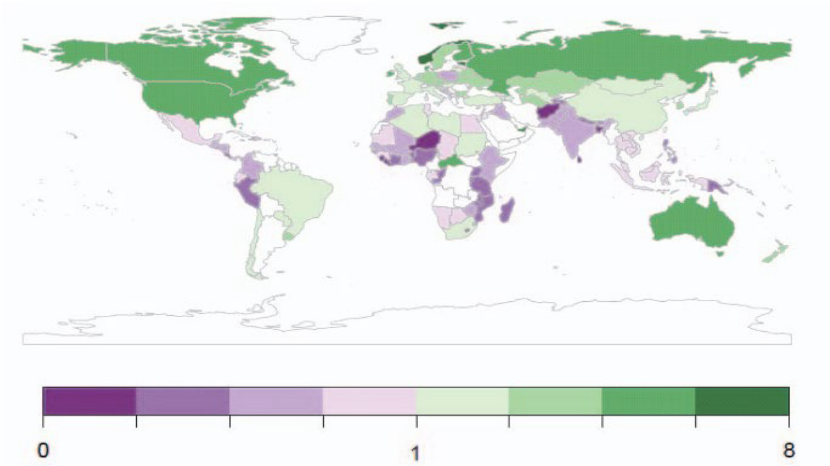


Figure 2.
Contribution and reception of global warming impacts

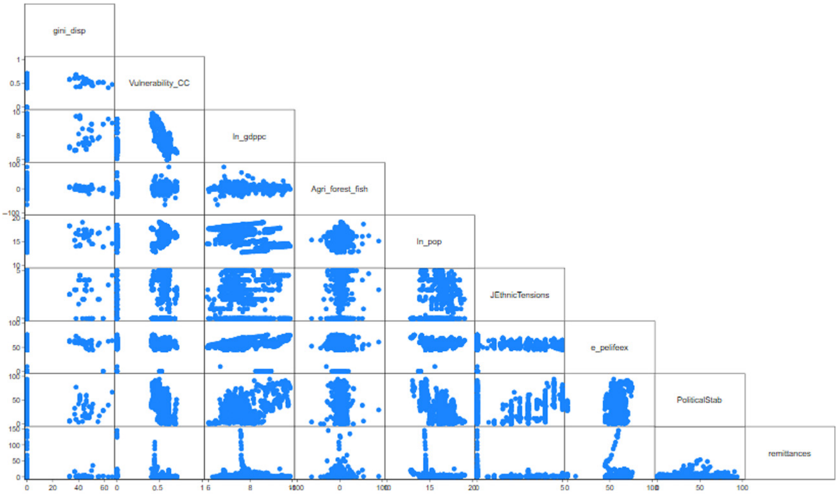
Notes: The Emission-Emergence ratio (logarithmic scale) relates the contribution of emissions to future impacts. A value greater than 1 means that a country is relatively more responsible for global warming than it will be impacted
Source: Frame *et al.* (2019)

responsible countries are the least vulnerable (Guivarch and Taconet, 2020). Change is further widening the gap between rich and poor. This situation leads to pessimistic forecasts for the future, given the vulnerability of the SSA region. For example, the Intergovernmental Panel on Climate Change (IPCC) predicts a high probability that global warming in SSA will exceed the COP21 target of keeping the increase in global average temperature below 2°C by the end of the century (IPCC, 2014). SSA would have low resilience due to the significant importance of its agricultural activity, its demographic pressure and its low level of development (Banque de France, 2020).

2.3 Climate change and income inequality are correlated

Figure 3 shows the strong correlation between climate change and income inequality in SSA. This observation reflects the low level of adaptation of the region in terms of variability to climate change-induced effects. Indeed, higher levels of CO_2 emissions can lead to higher temperatures, which can exacerbate health problems and reduce access to resources, such as food, water and housing, for low-income people. The scatterplot matrix shown in Figure 3 juxtaposes two-dimensional scatterplots that establish not only the relationship between vulnerability and climate change but also the correlations between each of the variables in the model.

However, this latter method of visually representing multivariate data has the disadvantage of decoupling the relationship between N variables into (N – 1) bivariate relationships. However, this disadvantage is largely offset by the simplicity of the presentation and the possibility of including a large number of variables in the matrix. This is why this method is the most widely used for visualizing multivariate analysis data, especially if the variables are numerical. However, only an econometric analysis will provide solid evidence, hence the focus of the following sections.



Source: Authors

Figure 3. Scatterplot matrix

Stylized evidence seems to support the view that climate change is further increasing income inequality in SSA. However, it is useful to present the interpretations of the literature and to identify possible channels through which climate change might be transmitted.

3. Literature review and theoretical positioning

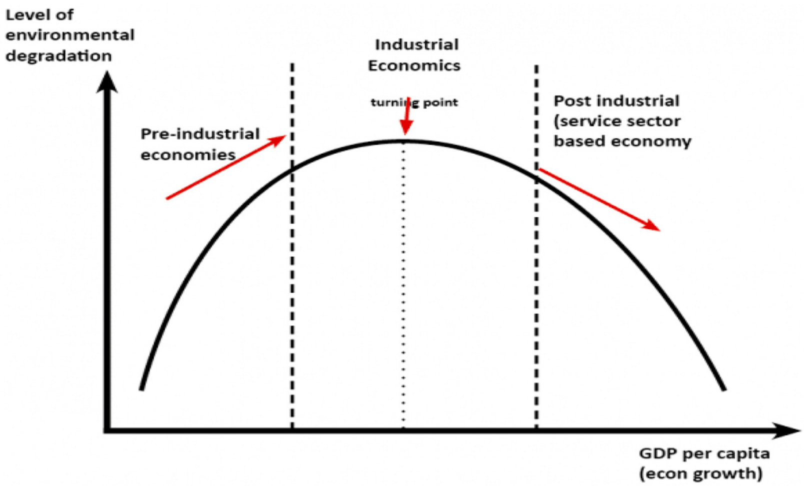
This section briefly presents the explanatory theories and empirical evidence on the effects of climate change on income inequality. It is also about identifying the gap and highlighting the blind spots in literature.

3.1 Theoretical background

Since the 1990s, the relationship between climate change and income inequality has been a fundamental part of the theoretical argument (Abid, 2016). The relationship is based on Kuznets' (1955) famous Environmental Kuznets Curve (EKC) theory. The EKC implies that environmental deterioration and per capita income have an inverted U-shaped relationship. This relationship was also developed by Grossman and Krueger (1991), who find that environmental deterioration would increase during the early stages of economic expansion, but after reaching a certain threshold of per capita income, economic growth would result in better environmental outcomes. In recent decades, the rising side of the EKC has disappeared as inequality in many low-income countries has increased (Palma, 2011). With reference to the Kuznets curve applied to both income inequality and environmental quality, Boyce (1994) assumes that the different outcomes mentioned above can be derived from the different paths of the Kuznets curve. Therefore, if countries follow the same trajectory of the Kuznets curve, there is a positive impact of inequality on environmental impact. If the environmental impact corresponds to the right-hand side of the Kuznets curve but income inequality has not reached the turning point at the same level of economic development and remains on the left-hand side of the Kuznets curve, a negative relationship between the level of inequality and pollution is recognized. The negative relationship between inequality and CO_2 emissions is observed when the U-shaped trajectory of a variable occurs instead of the inverted U shape. A non-significant relationship can be observed when the level of pollution or inequality of the country corresponds to the turning point. In practical terms, the countries of sub-Saharan Africa are generally located in the ascending part of the Kuznets curve (Figure 4), with levels of economic inequality rising initially with their economic development and the low level of industrialization that characterizes the region. However, the Kuznets model has its limitations in accurately describing the complicated reality of these nations because other institutional, social and political factors also affect how inequality evolves and do not always follow a uniform scheme.

Similarly, North (1990a, 1990b) sees climate change as a precursor to income inequality. He considers two types of drivers that can affect a nation's future economic growth: climate-related factors and socio-economic factors. Subsequently, the author argues that climate change affects income inequality between countries through uneven climate damages and differential mitigation costs. First, climate change is expected to reduce future income through direct losses of output and capital and lower economic growth. It is also expected to increase the need for investment in adaptation. These climate damages will be unevenly distributed across countries because physical impacts may differ and because vulnerability to climate change and adaptive capacity vary considerably between countries. The second manifestation of climate change on inequality can be seen through the transaction cost theory of Williamson and Masten (1995). The authors argue that the cost of GHG emission reductions will affect the future income of countries. Thus, climate change disproportionately affects the poorest within countries, between different regions and within cities. Without action to limit climate change, its impacts would continue to have an amplifying effect on inequality and could undermine development and poverty eradication. Theoretical developments on spatial inequalities have been affected by social-economic paradigms.

From a neo-classical perspective, regional development is based on the potential use of the region's own economic, social and natural resources, taking into account its internal development potential and fully pursuing the use and productivity of these intra-regional resources. A government subsidy, therefore, can only be used in the form of grants or tax rebates. However, the exogenous Keynesian approach is based on the need for government



Source: Pettinger (2019)

Figure 4.
The environmental
Kuznets curve

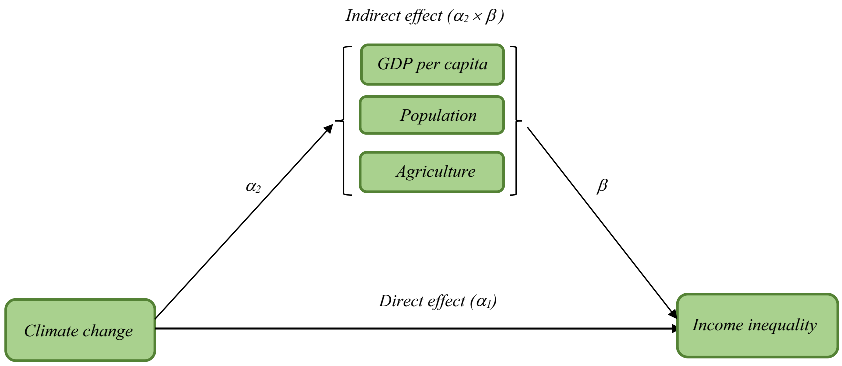
intervention to reduce the negative effect of climate change on income inequality. For Keynes (1936), market intervention would help to reduce regional inequalities.

3.2 Climate change and income inequality: an empirical overview

A burgeoning literature investigates the mechanisms by which climate change may reduce or increase income inequality. Most of the empirical investigations conclude with heterogeneous results. From this literature, we select GDP per capita, population and agriculture as potential channels (Figure 5).

Although Taconet *et al.* (2020) argue that damage assessment is a perilous exercise because it is very difficult, if not impossible, to predict how each country will be impacted by climate change, a large body of literature suggests that the overall damage of climate change will be greater in the poorest countries (Oppenheimer *et al.*, 2015; Tol *et al.*, 2004; Mendelsohn *et al.*, 2006; Burke *et al.*, 2015; Nordhaus and Yang, 1996; Hallegatte and Rozenberg, 2017; Dell *et al.*, 2012). Climate change affects people and countries unevenly. Indeed, the poorest populations and countries are the most vulnerable to the impacts of climate change, as they are more exposed and sensitive (Guivarch and Taconet, 2020). Climate change further widens the gap between rich and poor. Byers *et al.* (2018) show that Africa and South-East Asia have about 90% of the exposure to climate risks.

In less developed countries, it is observed that wealthy households tend to locate in areas of high climate risk because they find more affordable land there. As a result, the poor are often forced to live in flood-prone areas (Brouwer *et al.*, 2007). Jongman *et al.* (2015) argue that without emission reductions, the number of people at risk may increase by 10% in 2030. Furthermore, when a natural disaster occurs, the number of deaths is 10 times higher in the poorest countries than in the richest countries (Strömberg, 2007). The work of Baarsch *et al.* (2020) shows the vulnerability of SSA economies to rainfall and temperature fluctuations. Indeed, they show that inequalities between countries are expected to increase under a high warming scenario compared to low and no warming scenarios. However, the effects of climate change on poverty and income inequality may increase even when mitigation measures are taken by countries (Campagnolo and Davide, 2019). Climate change also affects the poorest people indirectly through the increase in agricultural commodity prices resulting from lower yields (Hallegatte and Rozenberg, 2017). This situation would then exacerbate poverty in South Asia and SSA as food security is jeopardized (Hertel, 2016).



Source: Authors

Figure 5. Direct and indirect effect of climate change on income inequality

Deryugina and Hsiang (2014) and Heal and Park (2016) highlight the fact that high temperatures lead to a decrease in productivity, which in turn leads to a decrease in income for individuals.

Climate change has a negative impact on the economies of most tropical regions, both directly and indirectly (Abidoye and Odusola, 2015). This is particularly important because of the high dependence on rain-fed agriculture, which is the main livelihood for most of the population (Taconet *et al.*, 2020). Climate change is also a source of income volatility for the poor. Extreme temperatures and low levels of rainfall can reduce yields, increase the risk of food insecurity and increase levels of poverty and income inequality (Mouleye *et al.*, 2019).

On a panel of households from 21 regions in eight SSA countries, Dzanku *et al.* (2015) found that yield gaps due to climate variability and production conditions result in increased poverty. Indeed, higher temperature significantly affects agricultural productivity, farm income, and in turn causes income inequalities. The effect differs between temperate and tropical zones. In mid- and high-latitudes, crop suitability and productivity are expected to increase and expand northwards, while the reverse is true for most countries in tropical regions (Gornall *et al.*, 2010). Taconet *et al.* (2020) reiterate that climate change leads to income inequalities. Indeed, climate change reduces agricultural production, income and economic activity. Also, there is increased investment in adaptive capacity. These effects are unevenly distributed across countries, as is the capacity to adapt. Countries that are more dependent on agricultural activities are more affected than others (Oppenheimer *et al.*, 2015; Burke *et al.*, 2015, Hallegatte and Rozenberg, 2017).

Another group of authors investigates the link between climate change and income inequality by analysing household energy expenditure, direct household energy consumption and/or direct household carbon emissions by income group (Gençsü *et al.*, 2020; Rentschler and Bazilian, 2017; Rodriguez-Oreggia; Chapa and Ortega, 2017). These studies support the positive correlation between climate change and household income levels. In addition, these works argue that increased income inequality would be associated with higher levels of one or more of the following: direct fossil energy consumption and direct carbon emissions, precipitation, etc. Ye *et al.* (2017) support this logic by providing evidence in a study in Chinese regions that income inequality is correlated with carbon inequality due to household consumption patterns. A renewed interest in studies that assess the varying effects of total GHG emissions on households and on the income level of different socio-economic groups can also be observed in the literature (Weber and Matthews, 2008; Ummel, 2014; Strambo and González Espinosa, 2020). As such, the authors show that the rich consume much more total energy and generate more total GHG emissions, which in turn negatively affect the income of the poor.

From this non-exhaustive review of the literature, three lessons emerge. First, most studies only assess the effects of climate change in developing countries and very few in SSA specifically. Second, very few studies dwell on potential transmission channels. Yet SSA presents an interesting field of empirical investigation with regard to the region's vulnerability. As noted above, SSA is more affected by climate change than it is affected by it. Consideration of the transmission channels (Figure 5) provides a better understanding of the effect of climate change on income inequality, reveals the complexity of these effects and is important for the formulation of relevant recommendations. Assessing the effects of climate change on income inequality is crucial in the context of the COVID-19 health crisis and the war between Russia and Ukraine, given the renewed interest of policymakers in implementing inclusive environmental and SSA policies.

4. Data and methodology

4.1 Data

Data is drawn from two main sources: the WDI (2020), *Notre Dame Global Adaptation Institute* (ND-GAIN) database and the Standardized *World Income Inequality Database* by Solt (2009). The study covers 38 countries in SSA. Our time horizon covers the period 1991–2020. The choice of the period is dictated by the availability of data obtained simultaneously for the countries in the sample. The period covers the different evolutions of income inequalities and also the evolutions of vulnerability to climate change.

4.1.1 Dependent variable. Our dependent variable for capturing income inequality is the Gini coefficient of inequality at the national level and household disposable income (after tax, after transfer) from the SWIID. SWIID uses a custom multiple imputation algorithm for missing data to normalize observations collected from the United Nations University's Global Income Inequality Database (version 2.0c) and several other global sources [1]. Gini coefficient ranges from 0 (equal distribution of wealth in a population) to 100 (one person has all the wealth in a population) to measure inequality. This variable is widely preferred in contemporary literature over the World Bank's Gini index.

4.1.2 Independent variable. Our main explanatory variable is vulnerability to climate change, as measured by the ND-GAIN indices, which capture a country's overall susceptibility to climate-related disturbances. Specifically, vulnerability refers to "a country's exposure, sensitivity and adaptive capacity to the impacts of climate change" and includes indicators of six key life sectors: food, water, health, ecosystem services, human habitat and infrastructure. Since the ND-GAIN climate vulnerability index tends to be correlated with macroeconomic variables, such as real GDP per capita, we use a version of the index adjusted for income level. We therefore prefer this measure for climate change, as opposed to traditional measures such as CO_2 that are widely used in the literature, because it is more inclusive and allows us to capture the polysemic nature of climate change. According to Cutter *et al.* (2009), vulnerability refers to the susceptibility of a population, system or place to exposure to a hazard and directly affects the ability to prepare for, respond to and recover from hazards and disasters.

4.1.3 Control variables. Referring to an influential literature that shows that certain macroeconomic variables can influence income inequality either directly or indirectly, we choose the following as control variables:

- *Agriculture:* agriculture is the major activity in SSA. Its productivity is affected by weather conditions and soil fertility. Therefore, it seems important to take it into account, as the lower a country may be productive, the lower its income and the higher a country is productive, the higher its income. It was used by Bhatasara (2015);
- The *GDP per capita* has been used at current US$ as it helps to compare results across countries;
- *Ethnic tensions* and *political stability*. Conflicts refer to events for which normal ways of solving disputes fails. These events may involve individuals or groups which may be personally or politically motivated (Burke *et al.*, 2015); and
- *Remittances* which are transfers of funds of migrants to their friends and families in their home country affect income. Remittances will increase the income of households, and so it is an important factor which can help to reduce income inequality within and across countries.

A complete list of countries and descriptions of the variables are provided in Appendix 1 and 2, respectively. The descriptive statistics (Table 1) show small variations. It is generally accepted that small variations in the data lead to unbiased results. We note that the Gini inequality index at the national level and household disposable income is on average 45.5 for the countries. Vulnerability to climate change has a minimum value of 5.93 and a maximum value of 10.7. The value added of the agricultural sector is therefore very uneven, averaging 3.2% of GDP, with a minimum negative value of −65.65% of GDP and a maximum of 91.60%. GDP per capita is unevenly distributed among countries, with an average of US$2,213. Some countries have a minimum GDP/capita of 103, while others have a maximum of 25,243. On average, SSA countries receive 4% of their GDP in remittances from abroad. However, some countries receive nothing, while others receive up to 145% of their GDP in remittances. This already tells us that income may be unevenly distributed, leading to income inequality. The correlation matrix (Table 2) shows low interdependencies, suggesting the absence of multicollinearity problems between the dependent and explanatory variables.

4.2 Methodology

Here, we present the specified model, the estimation technique and the method for dealing with endogeneity

Variable	Obs.	Mean	Std. dev	Min	Max	Sources
gini_disp	1,140	45.509	7.013	33	66	SWIID
CC	1,140	0.451	0.21	0	0.705	ND-GAIN
GDP/capita	1,036	2,212.99	3,445.299	102.598	25,243.602	WDI (2020)
Agriculture	1,028	3.201	9.7	−65.959	91.606	WDI (2020)
Population	1,140	17,586,321	2,647,5268	0	1.959e + 08	WDI (2020)
Ethnic tensions	1,140	3.263	1.047	1	5	ICRG
Life expectancy	1,140	55.471	13.944	0	76.4	WDI (2020)
Political stability	760	−0.468	0.854	−2.648	1.042	WGI (2020)
Remittances	990	3.787	11.645	0	145.15	WGI (2020

Notes: *gini_disp* = Gini index of income inequality; CC = climate change (vulnerability)
Source: Authors

Table 1.
Descriptive statistics

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) *gini_disp*	1.000								
(2) CC	0.005	1.000							
(3) GDP/capita	0.029	−0.593	1.000						
(4) Agriculture	−0.075	0.008	0.010	1.000					
(5) Population	0.024	−0.029	−0.292	0.082	1.000				
(6) Ethnic tensions	0.054	0.352	−0.195	0.006	0.094	1.000			
(7) Life expectancy	−0.073	−0.349	0.211	0.049	0.147	−0.149	1.000		
(8) Political stability	−0.029	−0.089	0.403	−0.027	−0.565	0.144	0.045	1.000	
(9) Remittances	0.005	−0.160	−0.033	−0.064	−0.217	−0.217	−0.006	0.113	1.000

Source: Authors

Table 2.
Correlation's matrix

4.2.1 Model specification. The empirical model is derived from Ongo Nkoa and Song (2019), who adopted specifications that take into account inequalities in Africa. The reduced version of the model is given by equation (1) below:

$$gini\_disp_{i,t} = \alpha + \beta_1 CC_{i,t} + \lambda X_{i,t} + \mu_i + \nu_t + \varepsilon_{it} \tag{1}$$

Where $gini\_disp_{i,t}$ represents the income inequality of country i at time t; $CC_{,i,t}$ the climate change of country i at time t approximated by the climate change vulnerability index.

X is the vector of control variables that considers GDP per capita, agricultural, fishing and forestry activities and population size. Thus, μ_i captures the unobserved country-specific effects. v_t captures the time-specific effect common to all countries, and ε_{it} is the error term. However, α, β and λ are the parameters to be estimated.

The influence of the interactive variables is taken into account in model (2) below:

$$gini\_disp_{i,t} = \alpha + \beta_1 CC_{i,t} + \beta_2 Channels_{i,t} + \lambda X_{i,t} + \gamma V_{i,t} + \mu_i + \nu_t + \varepsilon_{it} \tag{2}$$

Where $\boldsymbol{V}$ takes into account the interactions. We consider interactions between climate change, GDP per capita, population and agriculture. Considering the interactions leads to equation (3) below:

$$\begin{aligned} gini\_disp_{i,t} = {} & \alpha + \beta_1 CC_{i,t} + \beta_2 GDPpc_{i,t} + \beta_3 Agriculture_{i,t} + \beta_4 Population_{i,t} + \lambda_1 X \\ & + \gamma_1 (CC \times GDPpc)_{it} + \gamma_2 (CC \times Agiculture)_{it} + \gamma_3 (CC \times Population)_{it} \\ & + \mu_i + \nu_t + \varepsilon_{it} \end{aligned} \tag{3}$$

4.2.2 Estimation method. Inspired by the literature, we use the GLS technique in the basic model. There are three strong reasons for using GLS. Without claiming to be exhaustive, the use of these econometric techniques provides at least three advantages (Davidson, 2000). Firstly, in the presence of lagged variables, it makes it possible to obtain unbiased, convergent and efficient estimators. Secondly, it considers unobservable factors that may have an impact on the attractiveness of countries, economic growth and trade openness (Rodrik, 2002). Thirdly, it allows for the correction of the simultaneity bias between the variables of interest and control (Wooldridge, 2013). However, the absence of autocorrelation in the residuals ensures that the estimators are obtained.

4.2.3 Endogeneity issue. Since income inequality is a dynamic process with high inertia based on past values, it becomes important to take this inertia into account. We introduce the lagged variable of income inequality into equation (3) to obtain the dynamic form as described by equation (4):

$$\begin{aligned} gini\_disp_{i,t} = {} & \alpha + \beta gini\_disp_{i,t-1} + \beta_1 CC_{i,t} + \beta_2 GDPpc_{i,t} + \beta_3 Agriculture_{i,t} \\ & + \beta_4 Population_{i,t} + \lambda_1 X + \gamma_1 (CC \times GDPpc)_{it} + \gamma_2 (CC \times Agiculture)_{it} \\ & + \gamma_3 (CC \times Population)_{it} + \mu_i + \nu_t + \varepsilon_{it} \end{aligned} \tag{4}$$

Where $gini\_disp_{i,t-1}$ represents the dependent variable lagged by one period. The advantage of dynamic models over static models is that more information about the dynamics of our dependent variable is considered, but there is a high risk of a high correlation between the error term and the lagged dependent variable, usually known as Nickell bias (1981). Another important problem is the endogeneity of our dependent variable. Theoretically, endogeneity can be due to reverse causality, measurement errors or omitted variable bias.

First, reverse causality may exist between climate change and income inequality, either increasing income inequality or, conversely, reducing it. Indeed, work by Crichton (1999) and Baarsch *et al.* (2020) shows the vulnerability of SSA economies to variations in rainfall and temperature. Conversely, Baek and Gweisah (2013) and Uzar and Eyuboglu (2019) found that income inequality increases environmental degradation in developed and developing countries. Liu *et al.* (2019) find that inequality increases climate change through CO_2 emissions in the short term and reduces them in the long term. Moreover, in low- and middle-income economies, inequality is negatively associated with climate change, including CO_2 emissions (Grunewald *et al.*, 2017). Second, measurement error. The data on which we capture climate change and income inequality may contain measurement errors, especially for African countries. Third, omission bias is a source of endogeneity because the empirical specification of the model may not consider all determinants of income inequality. Moreover, unobserved country characteristics may jointly affect both variables (Onana *et al.*, 2024). To avoid this, several other control variables will be added to the model. Ignoring the endogeneity problem in an estimate leads to a biased estimate. To deal with reverse causality, the lagged dependent variable is included in the model (Wooldridge, 2010).

To take advantage of the panel data, in the dynamic model we use the generalized moment method (GMM), whose generalized moment method-difference (GMM-D) estimator was introduced by Arellano and Bond (1991) and Arellano and Bover (1995). Subsequently, Blundell and Bond (1998) refined the GMM-D estimator by developing the GMM-S estimator, which is more appropriate for solving endogeneity problems. The advantage of the generalized moment method-system (GMM-S) model lies in the fact that it can correct for the endogeneity of the explanatory variables of interest and the other explanatory variables. While the GMM-S appears to be theoretically more efficient than the GMM-D, it uses more instruments than the GMM-D, which makes it particularly inappropriate when the individual dimension is small. However, the quasi-stationarity of the variables and the absence of autocorrelation of the residuals guarantee that these estimators are obtained. Given the increase in funding, we cannot exclude the risk of measurement errors. Thus, the desirable features of the GMM-S allow us to solve the problems of multicollinearity, endogeneity and omitted variable bias.

5. Results

We present in this section the results of the baseline model, the sensitivity analyses and finally the several robustness analyses.

5.1 Baseline results

Table 3 shows the results of the hierarchical regression performed to test the relationship between climate change and income inequality. With vulnerability as the only independent variable, the model is significant, and the results of model (1) show that exposure to 1-point vulnerability increases income inequality by 0.253 points. These results are consistent with the studies of Adger (1999), who find that the vulnerability of populations or countries to climate change has negative effects on income inequality. In other words, vulnerability to climate change contributes to increasing the level of income inequality within populations across countries because in an environment where people have difficulty adapting to climate change and are thus vulnerable, they face resource unavailability, negative effects on well-being and paradoxically on their income levels, thus creating income inequality. These results are also in line with those of Kahn *et al.* (2021) and Hanna *et al.* (2011), who explain that the less wealthy are vulnerable to the impacts of climate change due to their exposure to water stress, intensity of droughts or heat waves, losses in agricultural yields or degradation of natural habitats.

Table 3. Climate change and income inequality, GLS

Variables	Dependent variable: *gini_disp* Estimation technique: GLS				
	(1)	(2)	(3)	(4)	(5)
CC	0.253*** (0.146)	0.230** (0.012)	0.257* (0.138)	0.262* (0.139)	0.447*** (0.147)
GDP/capita					0.278*** (0.071)
GDP/capita_square				−0.013* (0.030)	−0.214*** (0.065)
Agriculture			−0.005* (0.003)	−0.005* (0.003)	−0.006* (0.003)
Population		0.029* (0.020)	0.029** (0.023)	0.031** (0.023)	0.049** (0.024)
Constant	−0.103** (0.050)	−0.543* (0.322)	−0.517 (0.364)	−0.553 (0.374)	−0.938** (0.384)
Observations	1,140	1,064	955	955	955
Countries	38	38	38	38	38
Wald chi2(5)	5.657	6.263	8.143	8.323	23.64
Prob > Chi 2	0.0017	0.0437	0.0432	0.0804	0.0003

Notes: *; **; ***denote significance at the 10, 5 and 1% thresholds, respectively. ( ) robust standard deviations. *gini_disp* = gini index of income inequality; CC = climate change
Source: Authors

For the control variables, we find that almost all have unexpected signs. Once the population growth rate is added to model (1), vulnerability as a predictor of income inequality remains significant but this time if at the 5% threshold (Model 2). The coefficient of vulnerability is 0.23, which again means that a 1-point change in vulnerability leads to a 0.23-point increase in income inequality. These results are consistent with those of Guivarch and Taconet (2020), who find that countries with income inequality are those most exposed to climate change vulnerabilities. Adding the population growth rate shows that it is significant at a threshold of 10% and that the population growth rate has a positive effect on income inequality.

Taking agriculture into account allows us to obtain model (3), in which vulnerability and the population growth rate have positive and significant effects on income inequalities, while agriculture has a negative and significant effect on income inequalities. Indeed, a variation of 1 point in agriculture reduces income inequality by 0.005 points. These results reflect reality, however, as many researchers argue that people who rely on agriculture for their livelihoods often face a lack of land ownership rights and control over what is grown on that land, which undermines their efforts to mitigate the effects of climate change. While these individuals have freedoms over land, they achieve productive outcomes that contribute to reducing income inequality (Bhatasara, 2015).

The estimated results contained in models (4) and (5) show that the variables that explain climate change have both positive and negative statistically significant effects on income inequality. Thus, vulnerability to climate change, GDP per capita and population growth contribute to increasing income inequality. On the other hand, GDP per capita (squared) and agriculture contribute to reducing income inequality. These results are similar to those of Chang *et al.* (2018), in which they examine the relationship between GDP per capita and measures of income inequality. They thus provide strong evidence of a positive correlation between growth and income inequality across frequencies.

The results in Table 4 show us the transmission channels of climate change effects on income inequality. We can immediately see that all the variables are significant except population. In model (1), the interacted variable of climate change and GDP per capita has a significant and positive effect on income inequality of 0,058 point. A 1-point increase in $CC^{*}GDP_{Pc}$ will lead to an increase in income inequality. This shows that GDP per capita do not attenuate the effect of climate change on income inequality. Instead, it widens the gap. This can be due to the fact that in SSA, there are insufficient mechanisms which help to reduce climate effects since these countries are not yet highly economically developed. In fact, SSA have not yet reached a point of GDP which permit them to strongly invest in better environmental conditions. This can be explained by the EKC, which shows that when a country has attained a high level of GDP, it can invest in better environmental conditions.

When we interact climate change and agriculture, it has significant but negative effect on income inequality. This thereby indicates that agriculture tends to attenuate the positive effect that climate change has on income inequality in SSA. This is because agriculture is one of the most important activities in SSA because it yields income to households. These results are in line with those of Bhatasara (2015), who explains that, when individuals have freedom over land, they achieve productive outcomes that can contribute to reduce income inequality. Further, when producers have control over what is grown on a specific soil, it can undermine their efforts to mitigate the effects of climate change. Interacting climate and change and population has no significant effect on income inequality.

5.2 Robustness check

Two robustness are mobilized: the first consists in taking into account additional control variables to eliminate any omission bias of the variables, and the second robustness consists

Variables	(1)	(2)	(3)
	Dependent variable: *gini_disp* Estimation technique: GLS		
CC	0.323** (0.142)	0.340** (0.145)	0.637** (0.146)
GDP/capita	0.049 (0.076)	0.070** (0.033)	0.070** (0.033)
Agriculture	−0.006* (0.003)	−0.004* (0.005)	−0.006* (0.003)
Population	0.045* (0.024)	0.043* (0.024)	0.051 (0.048)
CC*GDPpc	0.058** (0.032)		
CC*Agriculture		−0.051** (0.011)	
CC*Population			−0.019 (0.105)
Constant	−0.799** (0.389)	−0.782** (0.383)	−0.901 (0.775)
Observations	955	955	955
Countries	37	37	37
Wald chi2(5)	12.95	13.05	12.88
Prob > Chi 2	0.0020	0.0020	0.0028

Notes: *; **; ***denote significance at the 10 and 5% thresholds, respectively. ( ) robust standard deviations. *gini_disp* = gini index of income inequality; CC = climate change
Source: Authors

Table 4. Transmission channels of climate change effects on income inequality

in estimating the model by generalized moment methods (GMMs), in a system to eliminate the endogeneity problem of our dependent variable.

5.2.1 Additional control variables. To ensure endogeneity is effectively addressed, we use the results from the GMM estimator in the system to provide a couple of diagnostic tests [2]. Results in Table 5 show that vulnerability to climate change positively affects income inequality at a significant rate of 1%. A one-point increase in vulnerability will lead to a 0.677-point increase in income inequality. These results are similar to those of Mouleye *et al.* (2019). Indeed, the poorest populations and countries are the most vulnerable to the impacts of climate change, as they are more exposed and sensitive (Guivarch and Taconet, 2020). Climate change further widens the gap between rich and poor. Byers *et al.* (2018) show that about 90% of exposure to climate risks is in Africa and South East Asia. GDP per capita has a positive and significant effect on income inequality. A one-point increase in GDP per capita leads to an increase in income inequality of 0.253 points. Indeed, sub-Saharan countries are characterized by low incomes, which tend to reduce economic activity, technology and access to capital for investment. These factors can contribute to reduced income inequality. The interaction between vulnerability and GDP per capita shows a negative and significant effect rate of 5% on income inequality. A one-point increase in vulnerability*GDP per capita leads to a 0.135-point decrease in income inequality. This is because the country will invest in reducing the effects of climate change. This investment involves the acquisition of new technologies and the hiring of skilled workers. As a result, employment and wages will increase, which will help to reduce income inequality. As Garabedian *et al.* (2020) note, society will find ways to protect the environment because environmental protection is classified as a luxury. Agriculture and forestry have a negative and significant effect on income inequality. A one-point increase in agriculture leads to a 0.22-point decrease in income inequality. The interaction between vulnerability and agriculture also shows a negative and significant effect on income inequality at a rate of 1%. This is due to the fact that agriculture is the main activity in sub-Saharan countries. Thus, in the face of certain climatic conditions, they will find ways to adapt. As for the population, it can be seen that it is positively and significantly correlated with income inequality. This can

Variable	Dependent variable: *gini_disp* System-GMM (1)	(2)	(3)	(4)
$gini\_disp_{(t-1)}$	0.445*** (0.056)	0.341*** (0.012)	0.341*** (0.010)	0.331*** (0.010)
CC	0.729*** (0.261)	0.271*** (0.050)	0.281*** (0.041)	0.677*** (1.295)
GDP/capita	0.584*** (0.119)	0.158*** (0.022)	0.220*** (0.033)	0.253*** (0.025)
GDP/capita_square	−0.249*** (0.045)			
CC*GDP/capita		−0.135** (0.061)		
CC*Agriculture			−0.006*** (0.002)	
CC*Population				−0.681*** (0.076)
Agriculture	−0.004 (0.002)	−0.021*** (0.003)	−0.017*** (0.002)	−0.022*** (0.001)
Population	0.179 (0.192)	0.242*** (0.044)	0.378*** (0.046)	0.552*** (0.034)
Ethnic tensions	0.203*** (0.038)	0.022*** (0.002)	0.037*** (0.002)	0.010 (0.006)
Life expectancy	−0.057*** (0.013)	−0.021*** (0.002)	−0.027*** (0.004)	−0.018*** (0.004)
Political stability	−0.001 (0.003)	0.003 (0.002)	0.000 (0.002)	0.004* (0.002)
Remittances	0.166*** (0.023)	0.034*** (0.009)	0.067*** (0.005)	0.036*** (0.012)
Constant	0.198 (2.460)	−0.812*** (0.651)	−0.763*** (0.634)	−1.211*** (0.617)
Observations	644	644	644	644
Country	37	37	37	37
AR (1)	0.000	0.000	0.000	0.000
AR (2)	0.648	0.754	0.758	0.805
Instruments	20	23	22	25

Notes: *; **; ***denote significance at the 10, 5 and 1% thresholds, respectively. ( ) robust standard deviations. *gini_disp* = gini index of income inequality; CC = climate change (vulnerability)
Source: Authors

Table 5.
Indirect effects of climate change on income inequality (S-GMM)

be explained by the fact that an increase in population without an increase in income leads to a decrease in disposable income per capita. This tends to increase income inequality, as some sections of the population will always find it difficult to meet daily expenses. When we interact vulnerability and population, we find a negative and significant effect on income inequality.

Both ethnic tensions and political stability have a positive and significant effect on income inequality. Countries with ethnic tensions are not conducive to development. This reduces economic activity and employment, which tends to increase income inequality. Life expectancy has a negative and significant effect on income inequality. Remittances also have a negative and significant effect on income inequality at a rate of 1%. A one point increase in remittances leads to a 0.067-point increase in income inequality. This is because not everyone benefits from remittances. So income inequality will tend to increase.

5.2.2 Mediation thresholds. So far, we have used linear analyses to analyse the impact of climate change on income inequality in Africa. In the analyses that follow, we have identified per capita income, population size and agricultural activity as the channels through which this effect passes (Table 6). In this section, we make use of structural equation modelling. The use of this approach has two advantages for us: firstly, it serves as a robustness analysis, and secondly, it enables us to determine the thresholds at which these different channels mediate the relationship. Following the work of Song *et al.* (2023), Table 6 presents the estimates of the analysis using GDPpc, population and agriculture, respectively. Analysis of this table highlights two main results:

Table 6. Mediation effect

Dep. var.	(i) Mediator: GDPpc (1a) GDPpc	(1b) Income ineq.	(ii) Mediator: population (2a) Population	(2b) Income ineq.	(iii) Mediator: agriculture (3a) Agriculture	(3b) Income ineq.
Climate change	−0.120* (0.064)	0.398*** (0.071)	4.138** (1.790)	0.420*** (0.078)	−0.1153*** (0.0241)	0.3207*** (0.0657)
GDPpc		−0.153** (0.064)				
Population				−0.007* (0.004)		
Agriculture						−0.5151*** (0.0904)
Constant	−0.040 (0.040)	−0.130*** (0.023)	1.238 (0.970)	−0.126*** (0.026)	0.0995*** (0.0119)	−0.0852*** (0.0269)
Bootstrap	500	500	500	500	500	500
Obs.	1,140	1,140	1,028	1,028	1,140	1,140
	Mediating of GDPpc		Mediating of population		Mediating of agriculture	
Indirect effect (Sobel)	0.018		0.027		0.053	
Direct effect	0.398		0.420		0.327	
Total effect	0.380		1.652		0.380	
% of the total effect mediated	15%		17%		24%	

Notes: Zhao *et al.* suggest bootstrap test of the indirect effect, medsem uses the Monte Carlo test instead as it is less time-consuming and still acceptable (Jose, 2013) ***; **; *indicate significance at 1, 5 and 10% level, respectively. Robust standard errors reported in parenthesis
Source: Auteurs

(1) Climate change affects all three mediators, and the effects are statistically significant at the 10, 1 and 5% thresholds (Columns 1a, 2a and 3a); and
(2) The mediators have negative effects on income inequality (Columns 1b, 2b and 3b).

Overall, the results suggest that mediation has taken place when some of the influences of climate change are induced by the different mediators used. Noting that these mediations are all partial, GDPpc mediates the effect of climate change on income inequality at a threshold of 15%, population at 17% and agriculture at 24%.

6. Conclusion and policy implications

This paper assesses the direct effect of climate change and its transmission channels on income inequality in sub-Saharan Africa. Three main observations refine our problematic. First, the persistence of income inequality in most SSA countries, coupled with an unprecedented health crisis and the Russian–Ukrainian war, hinders measures to prevent and reduce national and international inequality. Second, climate change in SSA is increasingly worsening people's livelihoods, as much of the population depends on agriculture. Third, to fill an important gap in the literature, this paper takes a fresh look at the direct and indirect effects of climate change on income inequality in SSA. Based on these three facts, we have mobilized theoretical and empirical developments to build a model of which several variants have been estimated by the GCM method, the robustness of which has been proven by the System-GMM from a sample of 38 SSA countries over the period 1991–2020. Two main results emerge: first, vulnerability to climate change is positively and significantly associated with an increase in income inequality, thus confirming the assumed direct effect; second, the effects of climate change are transmitted through GDP/capita, population and agriculture. These results confirm the pessimistic hypothesis of the negative effect of climate change on the livelihoods of the countries' populations. These findings are robust to a more robust estimation method and to the addition of additional control variables.

Three main non-exhaustive policy recommendations are made: (i) implementing inclusive development policies consistent with climate mitigation and adaptation objectives; (ii) creating financial space from various sources (natural resource rents, tax revenues) to finance the social security of the most vulnerable; and (iii) strengthening agricultural resilience to climate-related adverse events, including financing for greenhouse agriculture (greenhouse farming). Despite the ambition of this paper, it does not cover the whole spectrum of analysis. Indeed, as a possible extension to this study, research could analyse the non-linear effect of the impact of climate change on income inequalities through recent methods such as panel smooth transition regression. In addition, alternative measures of climate change or country-specific analyses could be carried out for specific economic policy recommendations.

Notes

1. These include the Organisation for Economic Co-operation and Development (OECD) Income Distribution Database, the Socioeconomic Database for Latin America and the Caribbean generated by the Center for Distributive, Labor and Social Studies and the World Bank and Eurostat.
2. These include the Sargan/Hansen test for instrument validity of the non-overidentifying model and the AR (1) and AR (2) tests for first- and second-order serial correlation, respectively. Thus, in the different tables, the H0 hypothesis of instrument validity of the Hansen test is rejected. In

other words, the non-significance of the Hansen statistics indicates that the instruments used are valid and the model does not suffer from over-identification. Furthermore, the p-value of the AR statistic (1), which is significant in all tables, indicates that there is no first-order correlation in the model, and the non-significance of the AR statistic (2) indicates that there is no second-order correlation.

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Appendix 1. List of countries

- Angola
- Benin
- Botswana
- Burkina Faso
- Cabo Verde
- Cameroon
- Central African Republic
- Chad
- Congo
- Congo
- Cote d'Ivoire
- Eswatini
- Ethiopia

- Gabon
- Gambia
- Kenya
- Lesotho
- Liberia
- Madagascar
- Malawi
- Mali
- Mauritania
- Mauritius
- Mozambique
- Namibia
- Niger
- Nigeria
- Rwanda
- Senegal
- Sierra Leone
- Somalia
- South Africa
- Sudan
- Tanzania
- Togo
- Uganda
- Zambia
- Zimbabwe

Source: Authors

Appendix 2

Variable	Description	Sources
gini_disp	Gini of inequality at the national level and household disposable income (after tax, after transfer).	SWIID
CC	Overall vulnerability of the country to climate-related disturbances	ND-GAIN
Agriculture	Agriculture, forestry and fisheries, value added (% of GDP)	WDI (2020)
GDP/capita	GDP per capita (current US$)	WDI (2020)
Ethnic tensions	Ethnic tensions	ICRG
Population	Proportion of total population growth (%).	WDI (2020)
remittances	Personal remittances, received (% of GDP)	WDI (2020)
Political stability	Political stability and absence of violence/terrorism (index)	WGI (2020)

Source: Authors

Table A1. Variable descriptions and sources

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