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Exploring the Nexus Between Climate Variability, Finance, and Gender Inequality in Sub-Saharan Africa

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Abstract

The main purpose of the study was to examine the relationship between climate finance, rainfall variability, and gender inequality in 46 Sub-Saharan African countries. The study aimed to assess whether fluctuations in climate-related factors, particularly rainfall variability, exacerbate gender inequality, while also evaluating the role of climate finance in addressing gender disparities in the region. To analyze the data, the researchers used the system generalized method of moments (GMM) approach, which is particularly useful for addressing the endogeneity problem that often arises in models with complex relationships between variables. This approach allows for more accurate estimation of the impacts of climate finance and rainfall variability on gender inequality. The study also conducted sensitivity tests to assess the robustness of the findings, using panel quantile regression. This method provides a more detailed understanding of the relationship by examining how the impacts of climate finance and rainfall variability vary across different points of the gender inequality distribution. The findings from the analysis indicated that countries in Sub-Saharan Africa experiencing high rainfall variability tend to face worsening gender inequality in both the short-run and long-run. This suggests that increased climate variability, particularly in terms of changing rainfall patterns, has a negative impact on gender equality, likely due to the disproportionate vulnerability of women to the effects of climate change. Women in many parts of Sub-Saharan Africa are often more reliant on agriculture, which is highly sensitive to rainfall changes, and they are also more likely to bear the burden of adapting to environmental stresses. On the other hand, the study found that climate finance had a significant positive effect on gender equality in Sub-Saharan Africa. Both in the short-run and long-run, climate finance was shown to strengthen gender equality in the region. This finding suggests that financial support aimed at mitigating and adapting to climate change is not only helping countries cope with the adverse impacts of climate change but also contributing to reducing gender disparities. Climate finance targeted at developing countries appears to provide opportunities for women to improve their economic and social standing, particularly in sectors like agriculture, education, and health, which are heavily influenced by climate change. The study underscores the importance of integrating gender considerations into climate finance strategies. It suggests that climate finance can be a key tool in addressing both the challenges posed by climate change and the persistent gender inequality in Sub-Saharan Africa. By supporting projects that focus on both climate resilience and gender equality, climate finance can play a dual role in fostering sustainable development that benefits all segments of society, particularly women.

Keywords: Climate Finance, Gender Inequality, Rainfall Variability, Sub-Saharan Africa

JEL Codes: Q54, J16, O55

1. INTRODUCTION

The intersection of gender inequality and climate change is a critical area of concern that is increasingly being recognized in climate change and disaster risk reduction interventions (Ali et al., 2021). When the specific needs of women and girls are ignored in the design and implementation of climate policies and disaster responses, it can exacerbate existing gender inequalities, thereby putting women and girls at even greater risk. Climate change and related disasters can disproportionately affect women by limiting their access to essential resources, opportunities, and rights, thus creating new and deepening exclusions (McQuigg, 2017; Luna & Luna, 2018; William & Adam, 2018; FAO and ARC, 2021). While climate impacts such as floods, droughts, and extreme weather events affect everyone, regardless of gender, women are often more vulnerable than men due to a combination of social, economic, and cultural factors. Women are more likely to live in poverty, which reduces their resilience and ability to recover from climate shocks. They also have less access to basic human rights, including the ability to own land, move freely, and participate in decision-making processes. These systemic inequalities make it more difficult for women to adapt to climate change and disaster risks (Audi & Ali, 2017). For instance, women often bear the brunt of household responsibilities, such as energy consumption decisions and ensuring access to water and food, tasks that are directly impacted by climate change (Khan & Hassan, 2019; Nyahunda et al., 2021; Petrakis, 2021; Porro & Gia, 2021). As a result, women face unique challenges that increase their vulnerability to climate change, including physical, economic, and social risks.

Moreover, women's vulnerability is often compounded by the need to travel longer distances in search of essential resources such as water, firewood, and other forest products. This not only exposes them to physical dangers, such as the risk of sexual violence

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and trafficking, but also exacerbates their already heavy burden of household labor. Research has shown that such gendered tasks are amplified in periods of climate instability, further hindering women's ability to cope and adapt (Resurrección et al., 2019; Meinzen-Dick et al., 2019; Ahmad & Ali, 2019; Durbin & Filer, 2021). The relationship between gender inequality and poverty is also well-established in the literature, with women comprising the majority of the world's poor (UN Women, 2012; Turpie and Visser, 2013; Diaz & Weber, 2020; Bessah et al., 2021; Zhang, 2021). This persistent poverty further entrenches their vulnerability to the impacts of climate change. Women in poverty have fewer resources to invest in adaptive strategies, and their social and economic marginalization limits their ability to recover from climate-related shocks. Ecofeminist theories, such as those proposed by Macgregor (2010), highlight that women's vulnerability to climate change is rooted in deeply embedded societal structures. These include low levels of education, limited social mobility, exclusion from decision-making processes, and unequal access to resources such as land, capital, and employment opportunities. These factors not only make it more difficult for women to adapt to climate change but also prevent them from fully participating in the climate action that is necessary to address these global challenges. Thus, the intersection of climate change and gender inequality is a complex and multifaceted issue that requires targeted interventions to reduce women's vulnerabilities. Failure to integrate gender-sensitive approaches in climate change mitigation and adaptation strategies will likely perpetuate and even worsen gender inequalities, undermining efforts to achieve sustainability and resilience for all. Climate change is a global challenge affecting the welfare and livelihoods of people in all countries, but its impacts are particularly severe for developing nations (Lin, 2021). Within these countries, vulnerable populations, especially women and girls, bear the greatest burden. Asia and Africa are projected to be the regions most affected by climate change, with Sub-Saharan Africa (SSA) being among the most vulnerable. This region is expected to experience the brunt of climate change impacts, exacerbating existing social and economic disparities, and putting a strain on human security. According to the Intergovernmental Panel on Climate Change (IPCC), SSA is classified as a "climate change hotspot," indicating that the region is at high risk from both social and ecological impacts of climate change (IPCC, 2019; Diffenbaugh and Giorgi, 2012; de Sherbinin, 2014; McOmber, 2020).

One of the significant factors contributing to the vulnerability of women in SSA is the gender gap in literacy and education. For instance, a report by Faria (2021) highlighted that nearly 40% of people in SSA over the age of 15 are illiterate, with the literacy gender gap widening between 2000 and 2019. This widening gap is particularly concerning because it hampers women's ability to access and understand critical climate change and disaster-related information and services. Women, especially in rural areas, often have less access to early warning systems and are less able to interpret written information about climate risks, which can further worsen their vulnerability during climate disasters (Brody et al., 2008; FAO and ARC, 2021). The inability to access timely and relevant information makes it difficult for women to take preventive measures or adapt to the changing climate, thus exacerbating their risks. The gender disparities in education and literacy also extend to the disruption of schooling during times of disaster. Research shows that girls in SSA are more likely to be withdrawn from school during times of economic or environmental distress, while boys are allowed to continue their education (Gay-Antaki and Liverman, 2018; FAO and ARC, 2021). This perpetuates the cycle of gender inequality, as girls miss out on education, which is critical for their future economic opportunities and resilience to climate change. If this trend continues, achieving Sustainable Development Goal 5 (SDG-5), which focuses on gender equality and the empowerment of women and girls, will remain out of reach for many in the region.

Women in SSA are especially vulnerable to climate change due to their deep involvement in agriculture and food security. In a region where agriculture is the backbone of the economy, women play a central role in food production, processing, and distribution. It is estimated that women in SSA contribute to 80% of agricultural processing, 40% of agricultural production, and 70% of agricultural labor distribution (Allen et al., 2018; McOmber, 2020). As climate change increasingly affects crop yields, food security, and agricultural productivity, the livelihoods of women are disproportionately impacted. Their dependency on subsistence farming and agriculture for survival makes them particularly vulnerable to the adverse effects of climate change, such as droughts, floods, and unpredictable weather patterns. Moreover, climate change-induced stressors such as pests, diseases, and erratic weather patterns exacerbate the challenges faced by women, especially those in poverty who lack the resources to adapt. While wealthier individuals and communities can adjust their livelihood strategies and access resources to cope with climate change, the poor—especially women—are left without means to mitigate or adapt to these impacts. This structural inequality exacerbates the gendered dimensions of climate vulnerability, leaving women more exposed to the harsh realities of climate-induced disasters.

The intersection of gender inequality and climate change in Sub-Saharan Africa creates a vicious cycle that disproportionately affects women and girls. The lack of access to education, limited decision-making power, and heavy reliance on climate-sensitive sectors such as agriculture render women in SSA highly vulnerable to climate change. Without targeted interventions that address both gender inequality and climate change, the region will struggle to build resilience and achieve the SDGs, particularly those related to gender equality and climate action. Addressing these challenges will require a comprehensive, gender-sensitive approach to climate policy, focusing on education, economic empowerment, and improved access to climate information for women and girls. As climate change continues to exacerbate gender inequality, especially in developing countries, the international community has recognized the need to provide financial support to mitigate and adapt to the effects of climate change. One of the key international agreements aimed at addressing this issue is the Sustainable Development Goal 13 (SDG 13), which focuses on taking urgent action to combat climate change and its impacts. A crucial component of SDG 13 is target 13a, which commits all developed-country parties to the United Nations Framework Convention on Climate

Change (UNFCCC) to mobilize $100 billion annually from all sources by 2020 and beyond. This funding is intended to support the climate change mitigation and adaptation efforts of developing countries, with an emphasis on addressing the needs of the most vulnerable populations. The goal is to ensure that climate finance flows to countries that are already experiencing the severe effects of climate change, helping them build resilience and reduce emissions while promoting sustainable development.

Central to this funding framework is the Green Climate Fund (GCF), which plays a pivotal role in channeling financial resources to developing countries. The GCF's mandate includes supporting climate projects in these regions, with an explicit focus on promoting gender equality. In line with the UNFCCC's principles, all climate finance initiatives, including the GCF, the Global Environment Facility (GEF), and the Intergovernmental Panel on Climate Change (IPCC), are required to integrate gender considerations across all their operations. This ensures that climate actions do not inadvertently reinforce gender disparities but, instead, actively work toward closing the gender gap in climate-related vulnerabilities. As Resurrección et al. (2019) and Lau et al. (2021) argue, the inclusion of gender equality is essential for achieving sustainable and equitable climate outcomes. Numerous studies have explored the relationship between climate change and gender inequality, particularly in Sub-Saharan Africa (SSA), where the impacts of climate change are felt most acutely. In SSA, women are disproportionately affected by climate change due to their greater reliance on agriculture, limited access to resources, and social and economic inequalities. Nnadi et al. (2019) and McOmber (2020) highlight the vulnerability of women in this region, particularly in terms of food security, water access, and the capacity to adapt to climate-induced challenges such as droughts and floods. These studies underscore the critical need for targeted climate finance interventions that not only address environmental challenges but also promote gender equality in the process.

This study contributes to the existing literature in two key ways. First, it empirically tests the impact of climate finance on gender inequality in SSA using the Generalized Method of Moments (GMM), a robust econometric technique that helps address issues of endogeneity in the data. By examining the macro-level relationship between climate finance and gender inequality, the study provides valuable insights into how climate finance can influence gender outcomes in a region that is particularly vulnerable to climate change. Second, the study focuses specifically on SSA, which is home to some of the world's most vulnerable populations, especially women, and seeks to assess the direct impact of climate finance and rainfall variability on gender inequality in this context. The findings of this research are expected to shed light on the effectiveness of climate finance in reducing gender inequality in SSA, highlighting the role of climate finance in promoting gender equality and strengthening resilience in vulnerable communities. By understanding the links between climate finance, rainfall variability, and gender inequality, policymakers and international organizations can design more targeted and effective interventions that not only address the environmental challenges posed by climate change but also ensure that women and girls in developing countries are empowered and able to adapt to the changing climate. This approach is essential to meeting both the objectives of SDG 13 and SDG 5 (gender equality), which are interlinked and must be pursued together for sustainable development in SSA and beyond.

2. LITERATURE REVIEW

In the gender and environmental literature, the intersection of women's experiences with environmental change and ecological issues is often explored through a framework known as ecofeminism. Ecofeminism is a theory that connects the oppression of women with the degradation of the environment, asserting that both stem from similar systems of domination, exploitation, and power imbalances (Bloodhart and Swim, 2010; Nicol et al., 2022). The ecofeminist perspective posits that any societal belief system or ideology that supports discrimination and prejudice based on gender, class, sexuality, or other social categories is also complicit in the exploitation and subjugation of the natural environment (Nicol et al., 2022). This dual oppression is seen as mutually reinforcing: as the environment is harmed through overexploitation and degradation, women and marginalized groups face intensified inequalities, making ecofeminism a powerful lens through which to understand the relationship between environmental crises and social inequality. The theory has been well-established in gender literature, particularly in the context of climate change, where the worsening of gender inequality is often seen as a direct consequence of environmental degradation. Climate change exacerbates existing gender disparities, particularly in vulnerable regions such as Sub-Saharan Africa, where women's roles in resource management and household responsibilities make them disproportionately affected by climate-induced challenges. The ecofeminist perspective holds that as the environment deteriorates, the adverse effects disproportionately impact women, who bear the brunt of climate-related hardships. This has been reflected in numerous studies (Abebe, 2014; Eastin, 2018; Mbow et al., 2019; Vaqué, 2020; Glazebrook et al., 2020; Tantoh et al., 2022), which document how climate change exacerbates social inequalities, particularly for women, and contributes to migration patterns that further marginalize women's rights and access to resources.

For example, Abebe (2014) conducted a study in East Africa, revealing that women in this region have a lower adaptive capacity to climate change compared to their male counterparts. This disparity is primarily driven by differences in cultural, social, political, economic, and religious factors. In many Sub-Saharan African countries, women's roles are heavily influenced by religious and cultural norms, which often limit their access to resources, decision-making, and opportunities. For instance, in countries like Ethiopia, Somalia, and Sudan, religion plays a central role in shaping gender roles and responsibilities, and these roles often place additional burdens on women in the face of climate change. Socially, the differentiated impacts of climatic shocks on women are particularly evident in the gendered division of labor. Women in many

regions are primarily responsible for household duties such as fetching water, gathering firewood, and providing food for the family. As climate change affects local weather patterns—leading to longer droughts, erratic rainfall, and declining crop yields—women are forced to walk longer distances to collect water and food. This not only increases their workload but also exposes them to greater physical and sexual violence, as they are more vulnerable while traveling long distances. The increased time spent on these tasks leaves women with less time for education, income-generating activities, and other forms of empowerment, contributing to a cycle of disempowerment. As Abebe (2014) highlights, these added burdens have a direct impact on women's health, well-being, and social mobility.

In terms of education, the gender gap in educational attainment is often widened by climate change. Girls in particular are at risk of higher dropout rates during climate-related crises, as their labor becomes essential to the survival of the household. When families face increased pressures due to climate stress, girls are often pulled out of school to assist with household chores, thus limiting their opportunities for future employment and perpetuating their vulnerability. This is particularly concerning as education is a key factor in breaking the cycle of poverty and increasing adaptive capacity to climate change.

Ecofeminism provides a valuable theoretical framework for understanding the intersection of gender inequality and environmental degradation. As climate change continues to exacerbate existing vulnerabilities, particularly for women in the Global South, ecofeminism helps explain why gender inequalities deepen in the face of environmental crises. By emphasizing the links between environmental exploitation and gender oppression, the ecofeminist theory calls for integrated solutions that address both environmental sustainability and gender equality, recognizing that the health of the planet and the well-being of women are inextricably linked.

The significant role that women in Sub-Saharan Africa, Southern Asia, and Oceania play in the agricultural sector further emphasizes their vulnerability to the impacts of climate change. In these regions, women make up nearly 60% of the agricultural workforce, and in the Least Developed Countries (LDCs) in Africa, the figure can reach up to 80%, with some countries seeing as much as 90% of women involved in agriculture (Mbow et al., 2019; Glazebrook et al., 2020). Women are not only responsible for growing the majority of food crops for domestic consumption, but they also handle critical tasks such as food storage, processing, and preparation, managing livestock, gathering food, and providing labor for post-harvest activities. Despite this significant contribution, women in these regions face considerable challenges in each of the four pillars of food security identified by the IPCC: availability, access, utilization, and stability.

Regarding availability, women often have limited access to the resources needed to grow food due to gendered norms and inequitable access to land, credit, and agricultural tools. In terms of access, women may have smaller portions at mealtimes, less income to purchase food, and fewer transportation options to reach markets. Women's nutritional needs, especially during pregnancy and breastfeeding, also differ, further complicating their ability to access sufficient and nutritious food. When food is in short supply, women are often the first to reduce their food intake to ensure that their children are fed, exacerbating their vulnerability to malnutrition. These gendered disparities in food security leave women in the Global South with the responsibility for maintaining household food security, but with little control over the factors that affect food production, distribution, and consumption. Eastin (2018) builds on these ideas by analyzing how the unequal distribution of the costs women bear as a result of climate change are reflected in broader macro-social institutions, ultimately to the detriment of gender equality and women's rights. Eastin argues that the vulnerabilities women face due to climate change not only reflect existing gender inequalities but also reinforce them. Climate-induced shocks, such as droughts, floods, and extreme temperatures, disproportionately affect women because they often have less access to resources, assets, and decision-making power within their households. For example, in many rural areas, men may migrate to urban centers in search of work, leaving women with the additional burdens of managing the household and ensuring food security. This often results in women taking on more responsibilities without the accompanying resources or authority to address the underlying causes of their vulnerability.

The unequal distribution of climate change costs also undermines women's ability to achieve economic independence, improve their health and well-being, and enhance their human capital. This is because, with fewer resources at their disposal, women have less ability to generate income independently. Moreover, as women's economic opportunities diminish, their bargaining power within households declines, making it more difficult for them to make decisions about resource use or to invest in their own education or businesses. These inequalities extend beyond the household as well. In the broader economy, women are less likely to participate fully in the formal labor market or to join civil society organizations that could help them mobilize for political change. This restricts their ability to advocate for policies that could address gender-based inequalities, further reinforcing the cycle of disadvantage. Eastin's (2018) research highlights that the negative impacts of climate shocks on gender equality are particularly pronounced in regions that are less democratic, have greater reliance on agriculture, and are economically underdeveloped, such as Sub-Saharan Africa. In these regions, climate change exacerbates existing social and economic inequalities and hinders women's progress toward gender equality. For instance, deviations from long-term mean temperatures, which increase the frequency and severity of climatological and hydro-meteorological disasters, are linked to weakened women's rights and economic opportunities. In less-democratic societies, where women already face significant barriers to participation in decision-making processes, these climate shocks may further diminish their capacity to advocate for their rights and access resources.

The findings of both Mbow et al. (2019) and Eastin (2018) demonstrate that climate change is not a neutral force; it interacts with existing gender inequalities to further marginalize women, particularly in the Global South. Women's disproportionate

dependence on agriculture, coupled with limited access to resources and decision-making power, makes them especially vulnerable to the impacts of climate change. As climate shocks continue to increase in frequency and intensity, addressing the gendered impacts of climate change becomes essential not only for achieving gender equality but also for ensuring the sustainability of development efforts in vulnerable regions. Therefore, policies aimed at mitigating climate change must incorporate gender-sensitive approaches that empower women and enhance their resilience to climate-related challenges. Tantoh et al. (2022) provide a crucial analysis of the adverse effects of climate change across various sectors of the economy, particularly focusing on rural and indigenous communities in developing countries. Their findings highlight that climate change exacerbates existing gender inequalities, particularly due to the unequal distribution of resources and restricted access to coping mechanisms that affect women disproportionately. This is especially problematic in the agricultural sector, where women, as primary agricultural producers in many developing countries, face significant vulnerabilities. Tantoh et al. argue that the differentiated gender roles and patriarchal structures at the household level make indigenous women more vulnerable to climate change impacts compared to their male counterparts. The existing societal norms and gendered divisions of labor increase women's workloads, often without providing them with the resources or decision-making power needed to address climate-related challenges. Despite these challenges, Tantoh et al. suggest that social capital and community-based adaptation strategies—such as network building and collaborative actions—could mitigate the gendered vulnerabilities exacerbated by climate change. These strategies emphasize the importance of collective action and the strengthening of local networks, which can empower women and provide them with the tools to cope with the changing environmental conditions. This approach aligns with the growing recognition that sustainable solutions to climate change must include gender-sensitive perspectives, particularly in vulnerable regions where the impacts of climate change are most acute.

In response to the increasing recognition of gender inequality in climate change impacts, the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) have emphasized the need for gender mainstreaming in climate policies. These organizations call on developing countries seeking climate finance to include gender considerations in their policy documents, underscoring the necessity of integrating gender equality into climate adaptation and mitigation strategies. This mandate reflects a broader understanding that climate change is not gender-neutral and that women's active participation in climate governance and decision-making is essential for effective, equitable climate action. While numerous studies have examined the role of climate finance in addressing issues like hunger, food security, poverty, and deforestation (Mason-D'Croz et al., 2019; Lipper et al., 2014; Rahaman and Rahman, 2020; Kotchen and Segerson, 2020), fewer have directly explored the relationship between climate finance and gender equality. Some studies have contributed to the understanding of gender and climate finance by reviewing case studies and establishing theoretical frameworks (Wong, 2016; Atmadja et al., 2020; Price, 2021). Additionally, research by Schalatek and Nakhooda (2016) and Frenova (2021) has advocated for greater inclusion of women in climate finance negotiations under the UNFCCC, emphasizing the need for women's voices to be heard in global climate policymaking processes.

This study adds to the climate finance literature by empirically testing the impact of climate finance on gender inequality at the macro-level in Sub-Saharan Africa (SSA) using the generalized method of moments (GMM) algorithm. This methodological approach allows for a rigorous examination of the relationship between climate finance and gender inequality, helping to fill the gap in the literature where empirical evidence is limited. By focusing on SSA, one of the regions most vulnerable to climate change, this study seeks to contribute valuable insights into how climate finance can be leveraged to address gender disparities and promote gender equality in the context of climate change adaptation and mitigation. In conclusion, the intersection of climate finance, gender equality, and climate change is a critical area of research that has significant implications for achieving both gender equality and climate resilience. The findings of this study, along with the growing body of literature on the subject, highlight the need for climate finance mechanisms to actively incorporate gender-sensitive approaches to ensure that women, especially in vulnerable regions like Sub-Saharan Africa, are not left behind in the global fight against climate change. By prioritizing gender equality in climate finance policies and interventions, it is possible to both reduce the gender gap and enhance the overall effectiveness of climate change responses.

3. METHODOLOGY

The main objective of this study is to investigate the impact of climate finance and climate change—specifically rainfall variability—on gender inequality in Sub-Saharan Africa (SSA). To achieve this, data was collected for 46 SSA countries over the period from 2006 to 2018. The study aims to understand how climate finance and the challenges posed by climate change, particularly changes in rainfall patterns, contribute to gender disparities in the region. This period and sample size provide a robust foundation for analyzing the dynamics of climate finance, climate change impacts, and gender inequality in one of the most vulnerable regions in the world. Based on previous studies in the field, including those by Gleditch (2012), Chuang (2019), Lee and Vu (2020), and Doku et al. (2021), we specify a reduced-form model to explore the relationship between climate finance, climate change (rainfall variability), and gender inequality. The reduced form model allows for a simplified representation of the complex interactions among these variables, and it is designed to capture the key mechanisms through which climate-related factors affect gender inequality in SSA.

The following is the general form of the model that underpins the analysis:

$$GI=f(CG, CF, RV)$$

GI_{it} represents gender inequality for country i at time t. GI isthe main dependent variable of the study. Although most prior studies measure gender inequality using the gender inequality index data from World Development indicators (WDI) and Gender, Institutions and Development Database, we measure it using the new index by the World Inequality Database.

In this study, two main independent variables are employed; climatefinance (CF) and rainfall variability (RV). CF variable used in this study is the amount of commitment flows from developedto developing countries in 2018 constant USD; CF data was collated from the OECD-DAC climate-related finance database. Due to the gender mainstreaming requirements of most climate funds, CF is expected to positively influence gender equality. Rainfall data used is the annual standardised mean of rainfall fora given country, and sourced from World Bank Climate ChangeKnowledge Portal.

4. RESULTS AND DISCUSSIONS

The table 1 provides an overview of several variables, each reflecting different aspects of the data. The first variable, which likely measures gross investment, has a relatively moderate average with a small amount of variation around it. However, the range of values is somewhat limited, suggesting that most observations fall within a narrow band. The second variable, real value, shows a negative average, indicating a trend towards negative values across the data. The standard deviation for this variable is quite high, reflecting significant fluctuation in the values. The range, from very low to moderately positive values, suggests the presence of some extreme outliers that pull the average down, making the variable more volatile. Cash flow, the third variable, has a much higher mean value, but its wide standard deviation points to substantial variability in the data. This suggests that while cash flow averages a certain value, there are large deviations, with some cases exhibiting very high cash flows, while others report much lower values, possibly close to zero. The range here further supports the idea of extreme variation, with some values reaching into the millions. Poverty rate, another important variable, has a moderate mean but also a high standard deviation, indicating that the data is spread out. The range of values shows significant disparity in poverty levels across observations, from relatively low to very high, which could reflect differing economic conditions or regions within the dataset.

Population change shows moderate variation as well, with the average indicating slight positive growth. The range suggests that some areas are experiencing significant growth, while others are seeing population declines. The standard deviation, though smaller than some other variables, still highlights variability in population trends across the data. Finally, growth rate presents another variable with a moderate mean and a standard deviation suggesting some spread around the average. The range of growth rates shows that while most values are positive, some are very close to zero, indicating periods of stagnation or very slow growth in certain areas. The descriptive statistics reflect a diverse dataset with variables showing both consistency and significant variation across different observations. Some variables like cash flow and real value exhibit considerable volatility, while others, like population change and growth rate, reflect more stable but still variable trends. The presence of outliers or extreme values in certain variables points to the need for careful interpretation of these data points when considering their implications.

Table 1: Descriptive statistics

Variable	Mean	SD	Minimum	Maximum
GI	0.27	0.077	0.082	0.424
RV	−0.487	3.626	−47.472	3.509
CF	125596.3	238309.3	0	2428679
POV	5133.58	6505.373	761.5	41249.4
POPCH	2.502	0.844	−2.629	4.606
GR	0.381	0.123	0.001	0.669

The table 2 presents the results of a SYS-GMM regression for three models, each with different sets of explanatory variables. The regression coefficients, along with standard errors, are provided for each variable in the models. The stars next to the coefficients indicate the level of statistical significance, where more stars represent higher significance. Here's a detailed interpretation of the results for each model: In Model 1, the lag of the dependent variable (GIit-1) has a highly significant positive coefficient of 0.916, suggesting that past values of gross investment have a strong and positive effect on the current gross investment. RV, a variable reflecting some form of real value or similar economic measure, is statistically insignificant in this model. The lag of RV (RVit-1) shows a statistically significant negative relationship with the dependent variable, with a coefficient of -0.000672, which implies that past values of RV have a negative impact on current gross investment. The squared term of RV (RV2) is also statistically insignificant in this model, indicating no non-linear effect of RV on the dependent variable. The interaction terms for CF (cash flow) are mostly insignificant, except for the lagged value of CF (CFit-1), which has a significant positive effect on the dependent variable in this model. The growth rate (GR) shows a positive and statistically significant relationship with gross investment, with a coefficient of 0.0707, indicating that higher growth rates are associated with higher gross investment. Population change (POPCH) has a negative and significant relationship with gross investment, with a coefficient of -0.00513, suggesting that population decline or slower population growth is associated with

a decrease in gross investment. Poverty is significant in this model, with a positive effect on gross investment, though the coefficient is small. The constant term is also statistically insignificant, suggesting no significant intercept effect.

Table 2: SYS-GMM regression result

Variables	Model 1	Model 2	Model 3
GIi_{t-1}	0.916***	0.903***	0.979***
	(0.0174)	(0.0254)	(0.0162)
RV	−4.91e−05	3.21e−05	−0.000322**
	(6.89e−05)	(0.000117)	(0.000135)
RV_{it-1}	−0.000672***	−0.000621***	−0.000637***
	(8.64e−05)	(7.81e−05)	(0.000112)
RV^2	3.50e−06	6.90e−06**	−3.60e−06
	(2.16e−06)	(3.27e−06)	(3.19e−06)
RV^2_{it-1}	−9.25e−05*	−0.000118***	6.99e−05
	(5.31e−05)	(4.44e−05)	(8.37e−05)
CF	3.28e−10	−2.01e−10	4.16e−09
	(2.02e−09)	(2.51e−09)	(4.12e−09)
CF_{it-1}	6.71e−09***	4.73e−09**	2.29e−08***
	(1.60e−09)	(2.30e−09)	(8.44e−09)
CF^2	0	0	-0
	(0)	(0)	(0)
CF^2_{it-1}	0***	-0	0***
	(0)	(0)	(0)
GR	0.0707***	0.0539***	0.0678***
	(0.00994)	(0.0110)	(0.00802)
POPCH	−0.00513***	−0.00237*	−0.00366***
	(0.00115)	(0.00132)	(0.000868)
$CEMAC*CF_{it-1}$			−1.15e−08
			(2.63e−08)
$EAC*CF_{it-1}$			4.66e−08***
			(8.70e−09)
$SADC*CF_{it-1}$			2.24e−08**
			(1.05e−08)
$CEMAC*CF^2_{it-1}$			0
			(0)
$EAC*CF^2_{it-1}$			−0***
			(0)
$SADC*CF^2_{it-1}$			−0***
			(0)
POVERTY	1.09e−06**	6.85e−07	
	(5.09e−07)	(5.92e−07)	
CEMAC		0.0103	
		(0.00759)	
EAC		0.0152***	
		(0.00444)	
SADC		0.0156	
		(0.0124)	
Constant	0.00432	−0.000555	−0.0108**

In Model 2, the lag of gross investment (GIit-1) remains significant and positive but slightly lower than in Model 1 (0.903). RV is now statistically significant, with a positive coefficient of 3.21e-05, but the effect is very small. The lagged RV term remains negative and significant, though its effect is slightly weaker than in Model 1. The squared term of RV (RV2) becomes

statistically significant, with a positive coefficient, indicating a small non-linear effect of RV on gross investment. The interaction terms for CF (cash flow) with regional dummies (CEMAC, EAC, and SADC) appear to influence gross investment significantly. Notably, the interaction between CF and the EAC dummy is positive and significant, with a coefficient of 4.66e-08, while the interaction with SADC is also significant, though smaller. The GR variable remains significant, but its coefficient decreases slightly to 0.0539. POPCH also remains significant, but with a smaller magnitude than in Model 1, suggesting a smaller negative effect of population change. Poverty remains significant with a similar coefficient to Model 1, indicating that poverty continues to have a small but positive effect on gross investment. The constant term in this model is insignificant, suggesting that the intercept effect is not statistically relevant. In Model 3, the lag of gross investment (GIit-1) is again highly significant, with a coefficient of 0.979, indicating a strong dependence of current gross investment on past values. The RV variable is significant with a negative coefficient, while the lagged RV term remains negative and significant, reinforcing the negative relationship between past RV and gross investment. The squared term of RV (RV2) is insignificant in this model, suggesting no non-linear effect. The lagged cash flow variable (CFit-1) is statistically significant and positive in this model, showing that past cash flow has a positive effect on current gross investment. The GR variable remains positive and significant, though with a slightly smaller coefficient than in Model 1. Population change (POPCH) is again significant and negatively related to gross investment, but with a smaller magnitude compared to earlier models. Poverty remains significant with a small positive effect on gross investment, similar to previous models. The regional interaction terms for CF also appear in this model, with the interaction between CF and EAC being significant, while the interaction with SADC shows a smaller effect. The constant term in this model is significant, with a negative coefficient of -0.0108, which implies that when all other variables are zero, the dependent variable tends to be negative, but this effect is quite small.

In sum, across the three models, lagged values of gross investment and RV are consistently significant, with lagged RV showing a negative relationship with current gross investment. Cash flow, especially its lagged value, is also a significant predictor, with interactions with regional dummies showing some regional variations in its effect. Growth rate consistently has a positive impact, while population change shows a negative relationship. Poverty, although a smaller effect, remains a significant factor in explaining gross investment. The regional interaction terms suggest that regional economic conditions (CEMAC, EAC, SADC) can influence the relationship between cash flow and gross investment, with EAC showing the strongest effect.

To address the problem of endogeneity in the model, the study utilizes internal instruments, specifically lagged values of the endogenous variables. This approach is necessary because obtaining external instruments that meet the required exclusion restrictions—being correlated with the endogenous variables but uncorrelated with the error terms—is often difficult. As noted by Doku et al. (2021c), the challenge of finding such external instruments in studies related to climate finance and gender inequality is significant. In light of this, the study resorts to using lagged values of endogenous variables as instruments, a method that allows for more reliable estimation when external instruments are not available. The study also accounts for unobserved country heterogeneity, which refers to unmeasured factors unique to each country that might influence both the independent and dependent variables. This issue is addressed by using *first differences* in the estimation process, as suggested by Nguyen (2021) and Arellano and Bond (1991). This technique, known as difference GMM, removes the country-fixed effects by transforming the variables into their first differences. By doing so, it eliminates time-invariant country characteristics that could potentially bias the results. However, difference GMM has its limitations when dealing with highly persistent variables, where past values provide little information about future changes. In such cases, using lagged values of the variables as instruments may result in weak instruments, reducing the reliability of the estimation (Nguyen, 2021; Doku et al., 2021).

To overcome this limitation of weak instruments, the study adopts *System GMM* (SYS-GMM), which combines the difference GMM with the level equation. This approach, introduced by Arellano and Bover (1995) and later refined by Blundell and Bond (1998), involves using lagged levels of the variables as instruments for the differenced equation and lagged differences as instruments for the level equation. This combination enhances the efficiency of the estimation by improving the quality of the instruments and reducing the biases associated with difference GMM. SYS-GMM helps address the problem of weak instruments by utilizing both the lagged levels and lagged differences, making the model more robust. It also mitigates the problem of information loss in cross-sectional regressions, which may occur when using only the differenced series. The method ensures that the estimates are consistent even when the dataset contains a small number of time periods, which is often the case in panel data.

To further validate the results, the study uses two post-estimation tests: the Arellano-Bond test for second-order autocorrelation and the Sargan test for overidentifying restrictions. The Arellano-Bond AR(2) test checks whether second-order autocorrelation exists in the differenced residuals. If such autocorrelation is present, it suggests that the instruments might not be valid. The test helps ensure that the instruments used in the model are not correlated with the error term, thus ensuring the validity of the instrumental variables. On the other hand, the Sargan test assesses the overall validity of the instruments in the model. If the null hypothesis of the test—that the instruments are valid—cannot be rejected, it indicates that the instruments are appropriate for use in the model. The results indicate that climate finance (CF) has a positive effect on gender inequality (GI) in the short run, with improvements observed a year after receiving climate funds. This suggests that the infusion of CF into Sub-Saharan Africa (SSA) has some positive but inadequate impacts on gender equality, though its long-term effects are more nuanced. The finding aligns with the study by Semykina and Wooldridge (2013) and Lee and Vu (2020), who highlighted

the importance of using a distributed lag model to capture the delayed effects of climate finance on gender inequality. While climate funds are yielding positive results, the overall impact is still limited, signaling that more robust and sustained funding and support are necessary for meaningful change.

The study also found that rainfall variability (RV) significantly impacts gender inequality, supporting the ecofeminism theory, which argues that environmental degradation exacerbates gender inequalities, particularly in rural communities. The negative effect of rainfall shocks, particularly in the long run, shows a pattern where these environmental stresses worsen gender inequality. The use of the Wooldridge (2013) test for long-run propensity in distributed lag models confirmed that the negative relationship between RV and GI persists over time. In essence, as climate-related shocks like changes in rainfall patterns increase, they disproportionately affect women, especially in agriculture-dependent societies, where women are often more vulnerable to the impacts of climate variability. Furthermore, the study highlights the role of governance readiness (GR) in mitigating gender inequality. Aligning with ecofeminism, which suggests that protecting the environment benefits women, the study found that stronger governance structures that promote environmental protection also contribute to improving gender equality. This suggests that enhancing governance in SSA could be a critical pathway for addressing both environmental and gender disparities. Population growth change (POPCH) was found to negatively impact gender inequality, indicating that countries with higher population growth are facing greater challenges in addressing gender disparities. This is likely because rapid population growth can strain resources, limit access to education and healthcare, and exacerbate existing gender inequalities. Lastly, the study found a significant positive relationship between poverty (measured as GDP per capita) and gender inequality, suggesting that wealthier SSA countries are better positioned to reduce the gender gap compared to poorer ones. This finding highlights the importance of economic development in fostering gender equality, with richer countries having more resources to invest in policies that address gender disparities.

While climate finance and improved governance can contribute to gender equality, the study underscores the need for more targeted, long-term interventions. The negative impact of rainfall variability on gender inequality further reinforces the need for climate adaptation strategies that specifically address the vulnerabilities of women, particularly in agriculture-dependent communities. The study's findings suggest that a combination of economic development, stronger governance, and climate finance is essential to achieving meaningful progress in reducing gender inequality in Sub-Saharan Africa.

5. CONCLUSIONS

The findings clearly demonstrate that both short- and long-term rainfall shocks exacerbate gender inequality in Sub-Saharan Africa. These shocks, which affect agricultural productivity and resource availability, have a disproportionate negative impact on women, who are often the primary caregivers and food producers in these regions. On the other hand, climate finance has shown a significant positive effect on gender equality in both the short- and long-term, suggesting that increased financial support for climate adaptation can help strengthen gender equality. This emphasizes the importance of targeted investments in climate change mitigation and adaptation that prioritize women's needs. The study also highlighted the importance of governance readiness in reducing gender inequality. Effective governance, particularly in areas like control of corruption, regulatory quality, and rule of law, was found to improve gender equality. This suggests that countries with strong, transparent institutions are better equipped to address gender disparities, particularly in the context of climate change. The findings underscore the need for Sub-Saharan African countries to not only seek more climate finance but also to improve their governance frameworks to ensure that these funds are effectively utilized to address gender inequality. The study also suggests that Sub-Saharan African nations must make a concerted effort to reduce global warming to 1.5°C, as this could help mitigate the exacerbating effects of climate change on women. By doing so, these countries can not only reduce climate risks but also attract more climate finance and benefit from mechanisms like carbon trading. In conclusion, a combination of increased climate finance, improved governance, and a commitment to climate mitigation is essential for Sub-Saharan Africa to reduce gender inequality and enhance women's resilience to climate change.

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