Women in digital world: the role of climate vulnerability.

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Abstract:

The Covid-19 health crisis has demonstrated the importance of digital financial inclusion as an essential instrument for sustainable development and the sustainability of economies. Despite the increase in the adoption of digital financial services, women are still lagging behind in terms of digital financial inclusion. In recent years, a wealth of literature has analysed the causes of this lag. However, very little is known about the role of climate vulnerability. This paper contributes to the literature by analysing the effect of climate vulnerability on the level of digital financial inclusion of women in a sample of 140 countries globally over a period from 2014 to 2021. Using the ordinary least squares method, we find strong evidence of a negative relationship between climate vulnerability and women's digital financial inclusion. The results are robust to the addition of additional control variables, the consideration of regional heterogeneity and income level, and the use of competing estimators. Furthermore, the analysis of transmission mechanisms shows that this effect is amplified by the level of economic development and the remittances sent by migrants. The paper concludes that taking into account the negative implications of climate vulnerability is necessary to reduce the gaps between men and women and ensure better financial autonomy for the latter.

Keywords: Climate vulnerability, digital financial inclusion, gender, fintech

1- Introduction

The objective of this article is to evaluate the role of vulnerability to climate change in the gender gap in terms of digital financial inclusion. The Covid-19 health crisis demonstrated the importance of technological innovation, primarily the digitalisation of financial systems as an essential instrument for sustainable development and the sustainability of economies (Demirgüç-Kunt et al., 2021; Adegbite and Machethe, 2019). Digital financial inclusion refers to the use of fintech, bigtech, blockchain, and other digital technologies to expand access to and use of formal financial services to a large segment of the population. (Shen et al., 2021; Xun et al., 2020). According to the ITU (2021), digital financial inclusion will play an indispensable role in accessing financial services, reducing inequalities, and eliminating poverty in the coming years. This suggests that the use of digital financial services is likely to improve the living conditions of populations.

While more than two-thirds of adults worldwide own a mobile phone, over 1.7 billion of them do not have a bank account. (ITU, 2021). Over the past ten years, the number of adults with access to digital technologies and digital financial accounts has increased by 50%, rising from 51% to 76% between 2011 and 2021 (Demirgüç-Kunt et al., 2021). Despite this overall increase, women are still lagging behind in terms of digital financial inclusion. At the global level, men are 12 times more likely to have access to the internet and a mobile money account compared to women. Moreover, in developing countries, this gap widens with more than 52% of men compared to women. (UNDP, 2023). While 69% of women in developing countries own a mobile phone, only 19% of them are likely to use it to connect to the internet. Furthermore, ITU estimates show that in 2023, only 32% of women in Africa had access to the internet, compared to 90% in Europe, 88% in CIS countries, 84% in the Americas, 64% in Arab States, and 63% in Asia and the Pacific. Moreover, according to GSMA observations (2021), 28% of women are less likely than men to have a mobile money account. For example, in Senegal and Ghana, women are respectively 15% and 10% less likely than men to have a mobile money account.

Despite this gap, a wealth of literature is dedicated to highlighting the positive effects of digital financial inclusion for women. For the majority, it reduces gender inequalities through the acceleration of women's autonomy (Tripathi and Rajeev, 2023; Elouardighi and Oubejja,

2023; Ojo, 2022; Kofman and Payne, 2021); stimulates economic growth (Ozili, 2024; Le Quoc, 2024); increases women's social and financial autonomy (Kulkarni and Ghosh, 2021); reduces poverty (Holloway et al., 2017); and enhances food security through improved agricultural productivity. (Adegbite et Machethe, 2019). On the other hand, several determinants have been identified as being the cause of this differential. The studies estimate that socio-economic factors such as income, religion, education, inequalities, age, and marital status (Pradhan et al., 2024; Wandeda et al., 2023; Kulkarni and Ghosh, 2021), education and financial freedom (Tay et al., 2022), and institutional factors like the quality of governance and regulation (Mpofu, 2023; Adegbite and Machethe, 2019) are the cause of this delay. However, the issue of climate vulnerability has not yet been addressed.

Climate vulnerability refers to the extent to which a system is susceptible or unable to cope with the adverse effects of climate change, including climate variability and extreme phenomena. (McCarthy et al., 2001). It depends on the nature, magnitude, and pace of the climatic variations to which a system is exposed, its sensitivity, and its adaptive capacity. In recent years, the world has been facing sudden changes in weather conditions, manifested by the increase in the scale, duration, and intensity of natural disasters. (Mahmood et al., 2023). According to EM-DAT observations, between 1990 and 2023, the world recorded nearly 11,833 natural disasters, resulting in economic losses of 202.7 billion dollars just between June and September 2023. Moreover, the facts show that the occurrence of natural disasters has killed approximately 40,000 to 50,000 people per year over the past decade. (Ritchie et al., 2024). According to the UN Refugee Agency (2023), not only did climate-related disasters cause more than half of the new displacements reported in 2022, but nearly 60% of refugees and internally displaced persons now live in countries that are among the most vulnerable to climate change. This inability of economies to cope with climatic hazards manifests itself in an increasingly persistent pattern of vulnerability. To this effect, the IPCC (2023) concludes that in 2022, 3.3 to 3.6 billion people worldwide lived in environments vulnerable to climate change.

Knowing that women make up more than half of the world's population, they simultaneously represent the most vulnerable group to climate change. Indeed, the United Nations estimates that 80% of those displaced by climate change are women. According to a 2019 UNDP report, at least 60% of the deaths over the past 20 years due to extreme climate events involved women. Furthermore, the OECD estimates that women are 14 times more likely to die from a disaster than men. Due to these economic and social risks associated with climate

change, women face difficulties accessing digital financial services. Indeed, climate vulnerability exacerbates inequalities between men and women, especially since they are generally responsible for household management and do not possess any tangible or intangible assets. (Eastin, 2018). This limited access to resources influences access to services such as education, credit, and technology, which increases the lack of technical know-how to carry out transactions, necessary for digital financial inclusion. (Myamba, 2023). Moreover, vulnerability to climatic hazards increases women's dependence on their spouses, limiting their participation in household decision-making. Influenced by cultural practices and patriarchy, the use of finance, particularly digital finance, by women is a luxury that more than one cannot afford. (Kusimba, 2018). In light of these elements, we hypothesise that climate vulnerability hinders women's digital financial inclusion.

Theoretically, the effect of climate vulnerability on women's digital financial inclusion is explained by the economic development channel and the remittance flow channel. Indeed, studies show that environmental issues are a real obstacle to economic development (Alano and Lee 2016; Botzen et al. 2019); this idea is supported by Alagidede et al. (2016), who demonstrate that climate change significantly reduces economic performance. Moreover, the economic development of countries significantly influences the level of financial inclusion, as strong economic growth encourages more inclusive financial systems. (Evans, 2015). Moreover, climate vulnerability influences households' ability to migrate by depleting the resources necessary for migration (Kaczan and Meyer, 2020), which limits remittances. While remittances play a crucial role in promoting financial inclusion by significantly reducing the gender gap in financial inclusion (Abokyi, 2023).

Based on a sample of 140 countries, several results are observed. Overall, climate vulnerability reduces women's digital financial inclusion. Moreover, this result remains robust to the use of additional control variables, the use of additional measures of women's digital financial inclusion according to income levels, and the use of competing estimators. Furthermore, the results of the mediation analysis provide evidence that economic development and remittances play a role in mediating the effect of climate vulnerability on women's digital financial inclusion.

This study contributes to the literature on at least three points. First, it enriches the literature on two aspects. Indeed, it contributes to the improvement of the literature on the determinants of women's digital financial inclusion and the effects of climate vulnerability. To

this end, it constitutes, to the best of our knowledge, one of the first studies that analyses the effect of climate vulnerability on women's digital financial inclusion at the global level. Secondly, rather than analysing the direct relationship, this study identifies and analyses the transmission channels through which climate vulnerability affects women's digital financial inclusion. The conclusions of this study will enable policymakers to recognise the negative implications of climate vulnerability and provide necessary guidance to ensure the resilience of economies to climate change.

The rest of the article is presented as follows. Section 2 describes the channels through which the relationship is conducted. Section 3 presents the data and the estimation strategy. The results are presented in section 4, and section 5 finally concludes.

2- Climate vulnerability and women's digital financial inclusion: analysis of transmission mechanisms

Theoretically, climate vulnerability creates economic distortions that affect women's digital financial inclusion in the same way as the level of economic growth and migrant remittances.

- **Climate vulnerability and women's digital financial inclusion: the channel for economic development**

Economic development is often considered as the strengthening of autonomy and substantial freedoms that enable individuals to fully participate in economic life. (Amartya Sen, 1999). It focuses on the creation of new businesses, the development of innovative sectors, and the attraction of investments. (Backhaus et Schumpeter, 2003). Thus, the existing literature considers it an important determinant of financial inclusion and mentions that income is an important factor in explaining the level of digital financial inclusion of women in a country (Camara and Tuesta, 2014; Fungáčová and Weill, 2015; Tuesta et al., 2015; Evans, 2015; Kofman and Payne, 2021). It influences both immediate economic performance and long-term growth prospects. Thus, previous studies have highlighted increased economic expenditures for the most vulnerable countries and those affected by natural disasters and climate change (Cheema-Fox et al. 2022; Kling et al. 2021). Indeed, countries with strong economic growth generally have more inclusive financial systems that allow individuals to fully participate in financial life.

Furthermore, a persistent opinion in the literature is that continuous growth is incompatible with environmental sustainability, as the growth process requires the use of the environment. (Alagidede et al., 2016). Thus, authors mention that climate change could impact the size and productivity of the workforce as well as the capital stock, which would affect investment and consequently future production (Fankhauser et Tol, 2005; Hallegatte, 2005; Eboli et al., 2010; Bretschger et Valente, 2011; Lemoine et Kapnick, 2016). According to the hypothesis of Dietz and Stern (2015), Moyer et al. (2014), and Moore and Diaz (2015), climate change also exerts an effect on technological development, which would have a significant impact on economic growth (Solow, 1956).

- **Climate vulnerability and women's digital financial inclusion: the migrant remittances channel**

Several studies support the argument that remittances offer a wide range of benefits for households and the economy as a whole. In this vein, some studies have established a link between remittances and digital financial inclusion. (Gani, 2016; Aga and Peria, 2014; IFAD and World Bank, 2015). Indeed, remittances can improve access to and use of digital financial inclusion means by reducing some of the obstacles and costs. (Mannan et Farhana, 2023). By reducing obstacles, remittances from migrants create a starting point that allows for the creation of other inclusive and sustainable financial services, which could contribute to economic growth by creating a solid fund for investment. (FIDA et Banque mondiale, 2015). So, they play a crucial role in promoting digital financial inclusion by facilitating access to financial services, improving savings, and significantly reducing the gender gap in financial inclusion. (Abokyi, 2023). Furthermore, according to Ratha (2007), when households receive funds, it increases their income and provides financial resources to poor households.

Moreover, vulnerability to climate change has complex effects on remittances, influencing migration patterns, financial stability, and community resilience. Vulnerability to climate shocks (for example, droughts, floods, or extreme temperatures) can affect households' ability to migrate by depleting the resources necessary for migration. (Kaczan et Orgill-Meyer, 2020). Thus reducing remittances, which are proportional to the cumulative migrants over time, as migrants do not send funds just once but throughout their lives. (Benveniste et al., 2022). Moreover, as climate vulnerabilities increase, communities may become increasingly dependent on remittances for adaptation and economic survival. (Randazzo et al., 2023). This dependence can create a cycle in which remittances become a source of income that hinders local development, thus triggering a vicious cycle of economic stagnation and dependency,

known as a "remittance trap," given that these funds are considered unearned money. (Chami et al., 2018).

3- Data and methodology

This section presents the empirical approach used to analyse the effect of climate vulnerability on women's digital financial inclusion. Recently, researchers have turned to attempts to explain the differences in financial inclusion between genders around the world. Following these studies (Gosh and Vinod, 2017; Zins and Weill, 2016; Demirguc Kunt et al., 2015; Demirguc Kunt et al., 2013a), we examine the gender difference in access to and use of digital financial services. The sampling period covers only three periods: 2014, 2017, and 2021. Thus, we use the OLS method in a cross-sectional manner following the equation:

$$DIGF_i = \beta_0 + \beta_1 Vulnerability_i + Z_i'\gamma + \mu_i$$

In this equation, $Z_i'\gamma$ is a matrix comprising a set of control variables used in the literature, namely economic, historical, institutional, geographical and socio-cultural variables, as well as region-specific fixed effects that capture the unobservable heterogeneity specific to the regions. μ_i is an error term, reflecting factors that are idiosyncratic to country i, as well as omitted variables and functional form misspecification.

$DIGF_i$ represents the average of the global financial inclusion index focused on digital technology for women for the years 2014, 2017, and 2021. The information related to the use of financial services comes from the World Bank's Global Findex database, which is the most comprehensive database on financial inclusion in the world (Cabeza-García et al., 2019). This information is well-suited to measure the gender gap in access to financing, as it allows for direct observation of women's control over their assets. We use four main indicators, namely:

- Women who have an account in a bank or financial institution

- Women who have made or received a digital payment

- Women who have saved money in a financial institution or in a mobile money account

- Women who have borrowed money from a formal financial institution or via a mobile money account

To ensure the stability of our results, we use the following alternative measures.

- Women using the internet

- Women who have made a digital payment

- Women who have received a digital payment

- Women who have used a mobile phone or the internet to buy something

- Women who have used a mobile phone or the internet to pay bills

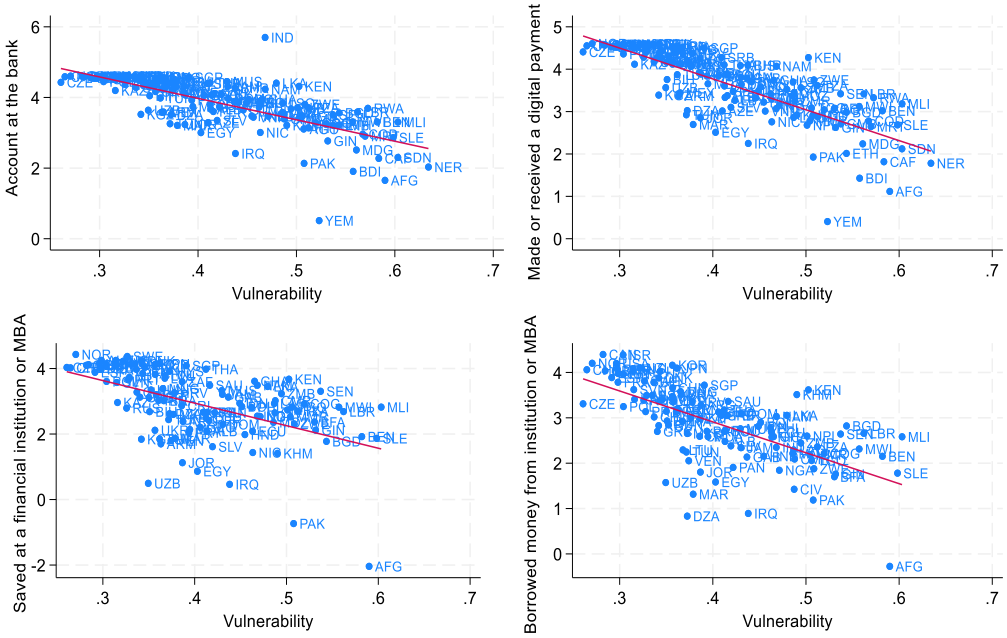
- Women who have used a mobile phone or the internet to send money

- Women who have used a mobile phone or the internet to access an account

$Vulnerability_i$ is the variable of interest which is measured by the climate vulnerability index provided by Notre Dame Global Adaptation Index (ND-GAIN). The index ranges from 0 to 1 and has the advantage of taking into account three aspects of climate change, namely the exposure, sensitivity and adaptability of economies to climate hazards. These factors are influenced simultaneously by social, institutional, geographical and economic factors (Foudjo et Keneck-Massil, 2024; Kling et al., 2021; Chen et al., 2015).

The relationship between vulnerability to climate change and women's digital financial inclusion worldwide is illustrated in Figure 1. It is observed that there is a negative relationship between vulnerability to climate change and women's digital financial inclusion, which confirms the initial hypothesis that vulnerability to climate change reduces women's digital financial inclusion.

Figure 1 : Correlation between vulnerability to climate change and women's digital financial inclusion



The control variables considered in this work stem from the array of determinants identified in the literature as explanatory variables for financial inclusion. These include education, unemployment, women's political empowerment, women in business and law, and the urban population.

Education is represented by the gross enrolment rate, which is the ratio between the total number of students enrolled, regardless of their age, and the population of the age group that officially corresponds to the indicated level of education. Many authors analyse the effects of education on financial inclusion and conclude that more educated individuals are more likely to be financially included (Allen et al., 2016; Fungácová and Weill, 2015). Moreover, the gender gap in formal financial inclusion is often due to women's lower financial literacy (Demirgüç-Kunt et al., 2013b).

Unemployment: refers to the portion of the labour force that is without work but available and actively seeking employment. Unemployment significantly affects digital financial inclusion by limiting financial resources and access to technology. Given that the likelihood of saving and formally borrowing is higher for employed individuals (Allen et al., 2016). When women are unemployed, they often do not have the disposable income necessary to invest in digital tools such as smartphones or internet connections, which are essential for

accessing digital financial services. Thus, the unemployed are more likely to report costs as a barrier to holding an account (Allen et al., 2016).

Urban Population: refers to people living in urban areas as defined by national statistical offices. The divide between urban and rural areas also plays an important role in the prevalence of bank accounts in developing countries. The literature shows that the probability of owning an account is higher in urban areas. People living in urban areas are almost twice as likely to frequently use their account (Allen et al., 2016).

Women in Business and Law: The index measures the impact of laws and regulations on women's economic opportunities. Thus, the authors observe that in countries where women are legally discriminated against in terms of work, family management, choice of residence, and inheritance of property, or are required by law to obey their husbands, women are less likely than men to own an account, save, and borrow (Larsson and Viitaoja, 2019; Demirgüç-Kunt et al., 2013).

The political empowerment of women refers to the presence of women in parliament. It corresponds to the percentage of parliamentary seats in a single or lower chamber held by women. The literature suggests that women's political autonomy can lead to financial inclusion, as women's participation in political leadership and decision-making through appropriate interventions can have a significant impact on women's economic autonomy (Sundstrom et al., 2017). Furthermore, women's political autonomy can impact physical infrastructure, literacy, access to accounts, and activity (Ghosh, 2022).

4- Results and discussions

i. Baseline results

The estimation results are presented in Table 1. Columns 1, 4, 7, and 10 present the bivariate relationship between vulnerability to climate change and the various indicators of women's digital financial inclusion. The results show that vulnerability to climate change has a negative impact on women's digital financial inclusion. The coefficient associated with this variable is statistically significant at the 1% level, with magnitudes suggesting that a one-point increase in the level of climate vulnerability reduces women's ability to have an account in a bank or financial institution, to make or receive a digital payment, to save money in a financial institution or in a mobile money account, and to borrow money from a formal financial institution or via a mobile money account by 6, 6.8, 7.2, and 6.8, respectively. Columns 2, 5, 8,

and 11 show the results considering regional fixed effects, while columns 3, 6, 9, and 12 take into account the inclusion of the determinants retained as control variables, which represents the basic specification for interpretation. Our results remain significant at the 1% level. Thus, these results support the current literature on the harmful effects of climate vulnerability because vulnerability to climate change creates multiple obstacles to financial inclusion. The most vulnerable and risk-exposed countries generally face higher financing costs and are more financially constrained. (Kling et al., 2021). This financial incapacity has significant implications, such as higher financing costs and financial exclusion. Thus, the results expand the current literature (Agoraki et al., 2024; Pankratz et al., 2023; Huang et al., 2022), showing that climate risk has a significant impact on financial decisions.

Table 1: Baseline results

VARIABLES	(1) Account	(2) Account	(3) Account	(4) Saved	(5) Saved	(6) Saved	(7) Digital	(8) Digital	(9) Digital	(10) Borrowed	(11) Borrowed	(12) Borrowed
vulnerability	-6.069***	-6.185***	-3.927***	-6.885***	-7.575***	-6.982***	-7.274***	-7.263***	-5.607***	-6.811***	-5.326***	-4.565***
	(0.504)	(0.874)	(1.317)	(1.279)	(2.150)	(2.137)	(0.531)	(0.927)	(1.390)	(0.814)	(1.578)	(1.701)
Education			0.202**			0.121			0.243**			0.138
			(0.102)			(0.185)			(0.115)			(0.143)
Unemployment			0.006			-0.195			-0.062			-0.217**
			(0.084)			(0.159)			(0.076)			(0.095)
Seats held by women			0.012			-0.194			-0.012			0.050
			(0.164)			(0.201)			(0.139)			(0.143)
Women Business and LIS			1.248***			2.164***			1.064***			1.387***
			(0.368)			(0.698)			(0.351)			(0.447)
Urban pop			-0.004			0.006			-0.038			0.045
			(0.048)			(0.055)			(0.031)			(0.037)
Asia		-0.134	0.385*		-0.930***	-0.156		-0.389***	0.114		-0.797***	-0.234
		(0.142)	(0.201)		(0.335)	(0.464)		(0.146)	(0.181)		(0.237)	(0.295)
Europe		-0.096**	-0.088		-0.581***	-0.504***		-0.146***	-0.140**		-0.593***	-0.432***
		(0.048)	(0.068)		(0.105)	(0.127)		(0.055)	(0.065)		(0.078)	(0.094)
Africa		-0.068	0.242		-0.254	0.346		-0.133	0.305		-1.000***	-0.415
		(0.193)	(0.235)		(0.437)	(0.455)		(0.222)	(0.229)		(0.340)	(0.318)
America		-0.182*	-0.076		-1.028***	-0.740***		-0.302***	-0.134		-0.798***	-0.593***
		(0.096)	(0.155)		(0.218)	(0.257)		(0.098)	(0.129)		(0.188)	(0.182)
Constant	6.402***	6.566***	-0.705	5.698***	6.643***	-3.024	6.681***	6.898***	1.224	5.635***	5.787***	-1.905
	(0.188)	(0.278)	(2.426)	(0.489)	(0.684)	(3.589)	(0.203)	(0.296)	(2.094)	(0.322)	(0.502)	(2.695)
Observations	137	133	121	112	109	103	137	133	121	112	109	103
R-squared	0.532	0.538	0.634	0.277	0.361	0.524	0.616	0.636	0.720	0.428	0.452	0.611

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

With regard to the control variables, it should be noted that women's education and score in business and law have positive and significant effects on women's digital financial inclusion. Also, women's digital financial inclusion is negatively influenced by unemployment. These results show expected signs according to the literature (Allen et al, 2016; Demirgüç-Kunt et al, 2013).

ii. Sensitivity analysis

To test the sensitivity of our results, we carry out a series of robustness tests, in particular: using additional control variables, using additional measures of women's digital financial inclusion, according to income levels and according to competing estimators.

- **Additional control variables**

To solidify our results, we analyse the effect of vulnerability to climate change on the various indicators of women's digital financial inclusion, taking into account additional control variables. Notably, the sociocultural variables are ethnic fragmentation, linguistic fragmentation, and religious fragmentation. Sociocultural/religious obstacles influence financial inclusion, particularly for vulnerable populations such as women who are generally financially excluded. (Handriks, 2019; Siddik, 2017). Institutional factors through the variable of political stability. Knowing that high-quality institutions, effective legal rules, rigorous contract enforcement, and political stability promote greater financial inclusion (Allen et al., 2016). Similarly, stability is characterised by institutional reforms that expand access to payment methods and other banking services, thereby improving economic development and financial inclusion. (Law, Azman-Saini et Hui, 2014; Morgan et Pontines, 2014). Geographical factors through distance to the equator and natural resources (Badeeb et al., 2023). For historical variables, we use the population density before colonisation up to the population density in 1500.

Table 2: Additional control variables

VARIABLES	(1) History Account	(2) Socio-cultural Account	(3) Geography Account	(4) Institution Account	(5) History Saved	(6) Socio-cultural Saved	(7) Geography Saved	(8) Institution Saved
vulnerability	-5.337***	-4.021***	-5.660***	-3.032***	-4.859**	-8.170***	-7.496***	-4.900***
	(1.272)	(1.332)	(1.475)	(1.020)	(1.829)	(2.101)	(2.523)	(1.649)
Pop density_1500	-0.039				-0.175**			
	(0.055)				(0.081)			
Ethnic		-0.107				-1.062*		
		(0.292)				(0.636)		
Language		0.446				1.020*		
		(0.283)				(0.535)		
Religion		0.153				0.737*		
		(0.226)				(0.423)		
Distance from the equator			-0.228*				-0.484	
			(0.136)				(0.406)	
Natural resources			0.006				0.013	
			(0.010)				(0.019)	
Political stability				0.257***				0.643***
				(0.070)				(0.129)
Constant	1.715	-0.294	0.974	0.583	-1.721	6.783***	-1.498	2.320
	(1.664)	(2.248)	(2.709)	(1.804)	(2.572)	(1.962)	(4.221)	(2.596)
Observations	89	121	90	121	69	103	70	109
R-squared	0.559	0.654	0.548	0.676	0.459	0.473	0.464	0.608
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	(1) History	(2) Socio-cultural	(3) Geography	(4) Institution	(5) History	(6) Socio-cultural	(7) Geography	(8) Institution
VARIABLES	Digital	Digital	Digital	Digital	Borrowed	Borrowed	Borrowed	Borrowed

vulnerability	-6.281***	-6.049***	-7.536***	-5.164***	-4.667**	-5.207***	-6.595***	-4.295***
	(1.261)	(1.262)	(1.287)	(0.824)	(1.846)	(1.527)	(2.105)	(1.312)
Pop density_1500	-0.151***				-0.233***			
	(0.049)				(0.056)			
Ethnic		-0.242				-0.535		
		(0.274)				(0.325)		
Language		0.470**				0.152		
		(0.195)				(0.276)		
Religion		0.340				0.657**		
		(0.240)				(0.317)		
Distance from the equator			-0.139				-0.298	
			(0.153)				(0.339)	
Natural resources			-0.165				-0.235	
			(0.149)				(0.364)	
Political stability				0.302***				0.394***
				(0.061)				(0.102)
Constant	2.817*	5.593***	3.230	3.606**	5.433***	4.953***	6.419***	5.104***
	(1.643)	(1.096)	(1.979)	(1.384)	(1.236)	(1.197)	(1.620)	(0.676)
Observations	89	121	90	133	69	109	70	109
R-squared	0.635	0.697	0.604	0.751	0.495	0.546	0.400	0.601
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

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

The results are reported in Table 2 above. We observe that the results remain significant at the 1% level with the addition of socio-cultural, geographical, and institutional variables. Regarding the addition of historical variables, the results remain significant at the 1% level for bank account ownership and the use of digital payments and significant at the 5% level for savings and borrowing funds via fintechs. This result can be explained by the fact that due to the slave trade, women were compelled to engage in economic activities, which more or less increased their ability to save and borrow from financial institutions. (Nvuh-Njoya et al., 2023).

- **Additional measures for the digital financial inclusion of women**

A specification based on alternative measures of women's digital financial inclusion is presented in Table 3 below. Even though the main measures used negatively influence the digital financial inclusion of women globally, it is also crucial to use other measures of digital financial inclusion for women to reassess the benchmark model. Thus, we analyse the effect of vulnerability to climate change on women using the internet (INT), women who have received a digital payment (RDIG), women who have used a mobile phone or the internet to buy something (PHIN), women who have used a mobile phone or the internet to pay bills (PHIN1), women who have used a mobile phone or the internet to send money (PHIN2), and women who have used a mobile phone or the internet to access an account (PHIN3).

Table 3 : alternatives measures

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	INT	PHIN	PHIN1	PHIN2	PHIN3	RDIG
vulnerability	-3.498***	-12.811***	-10.150***	-5.957**	-7.236**	-6.160***
	(1.251)	(1.806)	(2.126)	(2.344)	(2.868)	(1.435)
Education	0.558***	0.067	0.236	0.110	0.054	0.297**
	(0.153)	(0.156)	(0.186)	(0.198)	(0.240)	(0.117)
Unemployment	0.004	-0.149	-0.227	-0.264	-0.190	-0.043
	(0.084)	(0.116)	(0.149)	(0.188)	(0.138)	(0.076)
Seats held by women	-0.252**	-0.231	-0.298*	-0.199	-0.328*	-0.059
	(0.124)	(0.168)	(0.169)	(0.201)	(0.188)	(0.120)
Women Business and LIS	0.265	1.162**	1.516**	1.994***	1.592***	1.101***
	(0.271)	(0.536)	(0.604)	(0.737)	(0.606)	(0.349)
Urban pop	-0.001	-0.041	-0.009	0.045	-0.044	-0.048
	(0.027)	(0.052)	(0.052)	(0.061)	(0.066)	(0.032)
Asia	0.190	-0.062	-0.400	-0.265	-0.797**	-0.125
	(0.155)	(0.367)	(0.339)	(0.373)	(0.386)	(0.190)
Europe	0.007	-0.407***	-0.507***	-0.560***	-0.773***	-0.282***
	(0.056)	(0.111)	(0.137)	(0.141)	(0.153)	(0.068)
Africa	-0.219	-0.673	-0.228	0.393	-0.097	0.200
	(0.245)	(0.456)	(0.453)	(0.452)	(0.518)	(0.230)

America	0.278**	-0.804***	-0.726***	-0.588**	-1.216***	-0.397***
	(0.125)	(0.244)	(0.239)	(0.229)	(0.261)	(0.124)
Constant	2.769*	4.505*	1.208	-3.054	1.251	1.176
	(1.613)	(2.287)	(2.956)	(3.985)	(3.233)	(2.015)
Observations	87	118	118	102	117	121
R-squared	0.817	0.756	0.680	0.404	0.421	0.754

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

It follows that all additional indicators are negatively influenced by vulnerability to climate change. We also observe that the coefficients associated with the climate vulnerability index are higher in columns (2) and (3), which suggests that exposure and sensitivity to climate shocks have a greater impact on women's ability to use a mobile phone or the internet to purchase products and services and to pay bills. This is justified by the fact that climate vulnerability not only reduces livelihoods but also increases inequalities in access to technologies and digital infrastructures such as mobile phones and internet connectivity due to high costs (Evans, 2018).

- **Sensitivity by income level**

In light of the divergence in access to financial services worldwide, it is necessary to assess the relationship between vulnerability to climate change and the digital financial inclusion of women based on the income levels of countries. This will allow for the assessment of whether there were variations based on the four global income levels (low income, lower middle income, upper middle income, and high income). The results are reported in the following Table 4. All the coefficients associated with high-income countries are statistically significant at the 1% level. In middle-income countries, climate vulnerability influences women who have made or received a digital payment. However, there is no effect in low-income and lower-middle-income countries. This result is justified by the fact that the level of financial service usage is much lower in developing regions than in high-income countries. (Jukan et Softic, 2016).

Table 4 : Sensitivity by income level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	High income				Upper middle income				low and lower middle income			
VARIABLES	Account	Saved	Digital	Borrowed	Account	Saved	Digital	Borrowed	Account	Saved	Digital	Borrowed
vulnerability	-2.999***	-6.038***	-3.995***	-9.370***	-4.159	-2.210	-6.981**	-4.278	0.320	0.206	-0.703	0.479
	(0.801)	(1.676)	(1.003)	(2.633)	(3.221)	(7.777)	(3.270)	(3.344)	(1.672)	(3.923)	(1.753)	(2.837)
Education	0.054	0.229	0.117	0.136	0.142	0.332	0.068	-0.061	0.171	0.167	0.306**	0.326*
	(0.086)	(0.262)	(0.100)	(0.404)	(0.225)	(0.510)	(0.221)	(0.262)	(0.128)	(0.230)	(0.136)	(0.166)
Unemployment	0.026	-0.152	0.005	-0.064	-0.024	-0.162	-0.026	0.040	0.206	0.094	0.047	-0.398*
	(0.048)	(0.128)	(0.062)	(0.202)	(0.103)	(0.270)	(0.093)	(0.099)	(0.134)	(0.340)	(0.095)	(0.195)
Seats held by women	0.008	0.502***	0.004	0.307	-0.261	-0.491	-0.239	-0.521	0.065	-0.271	0.031	0.092
	(0.048)	(0.148)	(0.065)	(0.200)	(0.251)	(0.569)	(0.229)	(0.300)	(0.130)	(0.345)	(0.104)	(0.192)
Women Business and LIS	0.412***	1.101*	0.532***	0.370	0.488	0.376	0.468	1.477**	2.281***	3.224***	1.773***	1.146
	(0.137)	(0.544)	(0.182)	(0.459)	(0.632)	(1.155)	(0.590)	(0.670)	(0.522)	(1.075)	(0.370)	(0.689)
Urban pop	-0.018	-0.057	-0.020	0.035	-0.041	-0.004	-0.030	0.058	0.169	-0.023	0.016	-0.023
	(0.011)	(0.044)	(0.014)	(0.044)	(0.046)	(0.095)	(0.047)	(0.060)	(0.139)	(0.141)	(0.078)	(0.099)
Constant	3.651***	-0.442	3.233***	3.273	4.574	3.813	5.593	-0.785	-10.377**	-11.541*	-5.635**	-3.199
	(0.552)	(2.851)	(0.787)	(3.345)	(3.137)	(5.645)	(3.246)	(3.400)	(4.241)	(5.682)	(2.713)	(4.120)
Fixed effects region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	43	40	43	40	30	25	30	25	47	37	47	37
R-squared	0.721	0.724	0.739	0.641	0.350	0.402	0.450	0.550	0.578	0.468	0.581	0.412

Robust standard errors in parentheses

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

- **Alternative estimation techniques**

We analyse the robustness of our results through the general-to-specific (GETS: unrestricted general model) approach, which is similar to the Bayesian Model Averaging (BMA) method, and the non-parametric approach called quantile regression (Koenker et Bassett, 1982).

The general-to-specific (GETS) approach is adopted to determine which of the indicators used are relevant determinants of women's digital financial inclusion. It is one of the most commonly used econometric and statistical approaches for modelling model uncertainty (Ding et Knight, 2011). Thus, it is subjected to a series of stepwise statistical tests, the model that contains all potential explanatory variables (Hendry and Krolzig, 2004), which allows for the identification of variables that truly provide information. From there, the non-significant variables are gradually removed to simplify the model, resulting in a specific model that contains the most relevant explanatory variables. This model reflects economic theory and the relationships expected in the literature. The results show that the effect of climate vulnerability on the various indicators of women's digital financial inclusion is negative and significant in all specifications, thus confirming our hypothesis. Moreover, we introduce all the control variables, and only the significant variables appear in the table. These are education, unemployment, women's scores in business and law, urban population, linguistic fragmentation, and political stability.

Table 5 : GETS approach

VARIABLES	(1) Account	(2) Saved	(3) Digital	(4) Borrowed
vulnerability	-2.265**	-3.039**	-5.524***	-3.847***
	(0.972)	(1.196)	(0.560)	(1.033)
Education	0.208***			
	(0.078)			
Unemployment				-0.188**
				(0.076)
Women Business and LIS				0.751**
				(0.367)
Urban pop	0.094**	0.179***		0.116***
	(0.044)	(0.041)		(0.033)
Language	0.594***	1.153***	0.446***	
	(0.178)	(0.235)	(0.160)	
Political stability	0.449***	0.967***	0.377***	0.374***

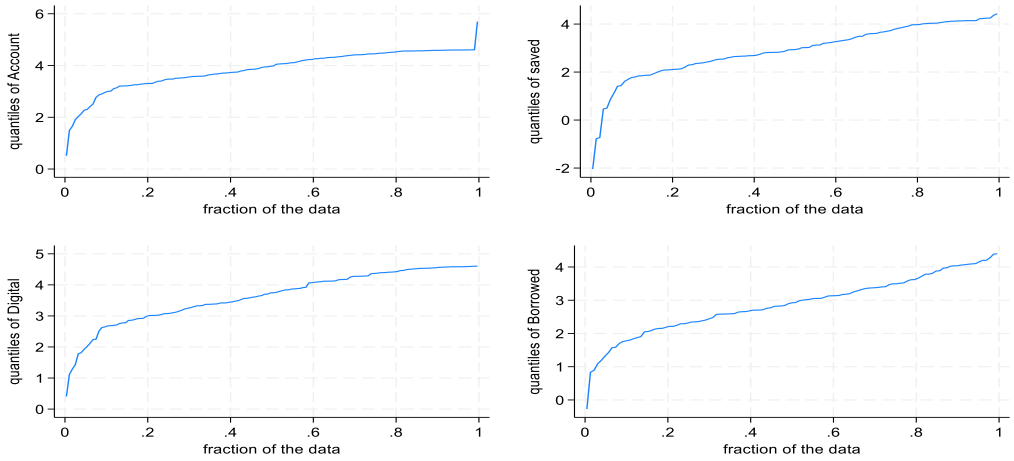
	(0.093)	(0.129)	(0.067)	(0.116)
Constant	2.420**	0.913	5.860***	-0.316
	(1.096)	(0.921)	(0.219)	(1.872)
Observations	124	112	137	112
R-squared	0.694	0.623	0.747	0.625

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To ensure the stability of our results, we analyse the effect of vulnerability to climate change using a non-parametric approach called quantile regression. This approach was first introduced in the foundational works of Koenker and Bassett (1978) and allows for the examination of the effect of vulnerability to climate change at different intervals throughout the indicators of women's digital financial inclusion. Additionally, this approach is more robust to abnormal errors and outliers, and it provides a richer characterisation of the data.

Figure 2 below represents the distribution of the dependent variables at different quantiles. When this distribution is wide, the mean can be very variable in the presence of strong heterogeneity in the sample.

Figure 2: Distribution of women's digital financial inclusion indicators at different quantiles.



The quantile estimator is obtained by solving the following optimisation problem for the θ^equantile (0<θ<1) :

$$min_{\beta \epsilon R^K}[\sum_{i\epsilon\{i:y_i \geq x'_i\,\beta\}} \theta|y_i - x'_i\,\beta| + \sum_{i\epsilon\{i:y_i < x'_i\,\beta\}}(1-\theta)|y_i - x'_i\,\beta| \qquad (5)$$

Where y_i is the digital financial inclusion of women i, β is the vector of parameters to be estimated and x_i is the vector of explanatory variables.

The regression results are presented in the following Table 6. Columns 1 to 5 present the estimates for the 10th, 25th, 50th, 75th, and 95th percentiles. It follows that climate vulnerability has a negative effect on women's digital financial inclusion at all intervals. This effect varies throughout the distribution of women's digital financial inclusion indicators. We observe that at the 95th percentile, the effect of climate vulnerability on women's digital financial inclusion is almost non-existent, which suggests that at higher levels of women's inclusion, they implement measures to counter the negative effects of climate vulnerability, especially since women are identified as change agents. This supports the observations of Li et al. (2024), Ganda (2024), and Achuo et al. (2022), who postulate that the financial empowerment of women improves the quality of the environment.

Table 6: quantile regression

VARIABLES	(1) Q10	(2) Q25	(3) Q50	(4) Q75	(5) Q95
Account					
Vulnerability	-4.616**	-2.843**	-2.820***	-3.275***	-1.520
	(1.899)	(1.278)	(0.953)	(0.892)	(1.722)
Constant	-2.715	-3.526	1.074	4.845***	3.611
	(3.142)	(3.304)	(2.787)	(1.320)	(3.337)
Observations	124	124	124	124	124
Pseudo R2	0.5233	0.4823	0.4719	0.3638	0.1389
Saved					
Vulnerability	-3.485	-9.296***	-5.700**	-3.852	-2.907
	(5.649)	(2.808)	(2.222)	(2.356)	(2.301)
Constant	-12.098	-3.861	-0.348	2.583	4.411

	(7.930)	(5.078)	(5.103)	(4.027)	(2.903)
Observations	105	105	105	105	105
Pseudo R2	0.3310	0.2697	0.2918	0.3061	0.2888
Digital					
Vulnerability	-5.746***	-5.493***	-4.465***	-3.515***	-4.819**
	(1.923)	(1.492)	(1.373)	(1.167)	(1.904)
Constant	-4.418*	-1.018	-0.330	3.258	6.295***
	(2.623)	(3.140)	(3.193)	(2.489)	(2.288)
Observations	124	124	124	124	124
Pseudo R2	0.5377	0.5134	0.5113	0.4503	0.2767
Borrowed					
Vulnerability	-4.335*	-5.690***	-5.744***	-4.692***	-4.312*
	(2.409)	(1.660)	(1.352)	(1.307)	(2.420)
Constant	-7.666	-5.045*	-1.192	3.863	1.517
	(5.268)	(2.807)	(3.835)	(3.238)	(3.961)
Observations	105	105	105	105	105
Pseudo R2	0.3966	0.3848	0.3964	0.4010	0.3799

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

iii. Transmission channels analysis

In this section, the aim is to empirically test the mediating variables through which climate vulnerability influences women's digital financial inclusion and to determine the contribution of each mediating variable. Thus, the approach followed in this study is causal mediation analysis inspired by MacKinnon et al. (1995). To this end, two mediators were identified: economic development measured by the Gross Domestic Product (GDP) of the countries and total remittances measured as a percentage of GDP. All this data was obtained from the World Development Indicators database. (WDI). The percentage of the mediated effect by the channels in the relationship between climate vulnerability and its influence on women's digital financial inclusion will therefore be determined, as shown in Figure 3 below.

This approach therefore involves the subsequent estimation of two regression equations, as follows:

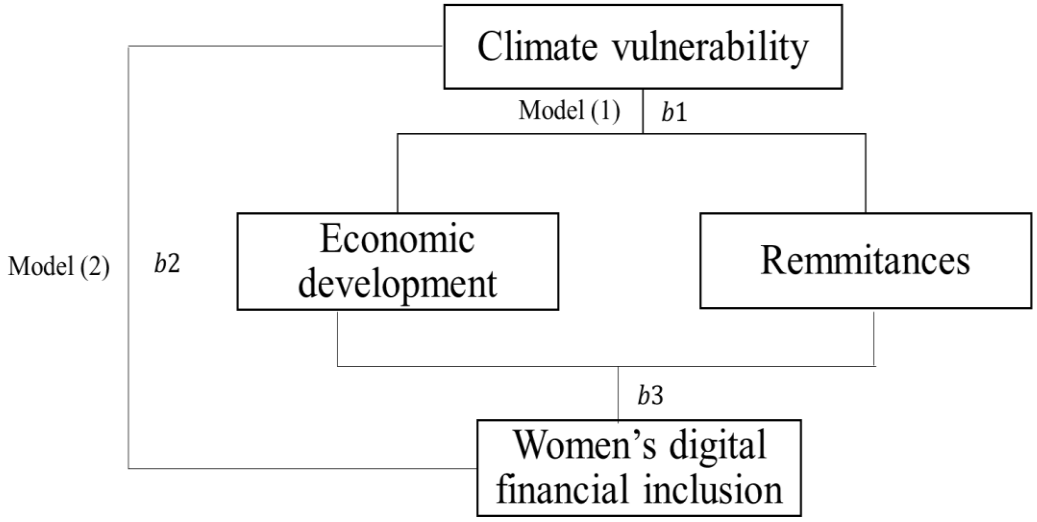
Model 1 : $Med_{it} = a_1 + b_1 VCC_{it} + c'_1 X_{it} + \mu_{it}$ (a)

Model 2 : $INCLUSION = a_2 + b_2 VCC_{it} + b_3 Med_{it} + c'_2 X_{it} + \mu_{it}$ (b)

Where Med_{it} represents the mediation variables. The composition effect is derived from the above two models as follows:

Effet indirect : $b_1 * b_3$; **Effet direct** : b_2 ; **Effet total** : $(b_1 * b_3) + b_2$

Figure 3 : Mediation effect



Source : *Adapté à partir des travaux de Mackinnon (1995)*

The approach involves estimating two models, as illustrated by the graph above. First, the parameter (b1) describing the indirect relationship between climate vulnerability and the mediators (economic development and remittance flows). Next, model (2) is estimated by regressing climate vulnerability on women's digital financial inclusion while controlling for the mediators. The magnitude of this effect is provided by the coefficient (b2). The indirect effect is the difference between the total effect and the direct effect, measuring the degree to which climate vulnerability

influences the digital financial inclusion of women through mediators (economic development and remittance flows).

Table 7 presents the results of the mediation of the effects of climate vulnerability on the digital financial inclusion of women. This is done based on several statistical approaches popularised by Mackinnon. (1995). Considering the channel mediation effect, the three indirect effect tests (Sobel, Aroian, and Goodman) are different from zero. Moreover, the results suggest that the channel mediation effect is quite substantial and that 77%, 96%, 66%, and 72% of the effect of climate vulnerability on women's digital financial inclusion is mediated by economic development. Indeed, climate change affects social well-being, which negatively influences economic development. (Alagidede et al., 2016). Similarly, countries with low economic growth generally have less inclusive financial systems. (Evans, 2015). Furthermore, 26%, 52%, 30%, and 31% of the effect of climate vulnerability on women's digital financial inclusion is mediated by remittance flows.

Table 7: Mediation analysis

	Economic growth			Flow of migrants' funds		
	Coef.	Std err	P-value	Coef.	Std err	P-value
Account						
(A) Test de médiation						
Sobel	-2.570	0.843	0.002	-0.730	0.380	0.055
Aroian	-2.570	0.847	0.002	-0.731	0.389	0.060
Goodman	-2.569	0.839	0.002	-0.732	0.371	0.049
(B) Composition des effets						
Effet indirect (Sobel)	-2.570	0.843	0.002	-0.730	0.380	0.055
Effet direct	-0.765	1.192	0.000	-2.019	0.945	0.055
Effet total	-3.335	0.918	0.000	-2.749	0.898	0.033
% de l'effet total médié		0.770			0.265	
Saved						
(A) Test de médiation						
Sobel	-6.795	1.550	0.000	-2.589	0.976	0.008
Aroian	-6.795	1.559	0.000	-2.588	0.993	0.009
Goodman	-6.795	1.540	0.000	-2.587	0.959	0.007

(B) Composition des effets						
Effet indirect (Sobel)	-6.795	1.550	0.000	-2.587	0.976	0.008
Effet direct	-0.255	2.041	0.000	-2.375	1.909	0.008
Effet total	-7.049	1.885	0.000	-4.964	1.872	0.008
% de l'effet total médié		0.964			0.521	
Digital						
(A) Test de médiation						
Sobel	-3.235	0.827	0.000	-1.286	0.440	0.003
Aroian	-3.235	0.831	0.000	-1.286	0.447	0.004
Goodman	-3.235	0.823	0.000	-1.286	0.434	0.003
(B) Composition des effets						
Effet indirect (Sobel)	-3.235	0.827	0.000	-1.286	0.434	0.003
Effet direct	-1.652	1.128	0.000	-2.940	0.860	0.001
Effet total	-4.887	0.896	0.000	-4.226	0.862	0.000
% de l'effet total médié		0.662			0.304	
Borrowed						
(A) Test de médiation						
Sobel	-3.379	0.991	0.001	-1.142	0.561	0.042
Aroian	-3.379	0.997	0.001	-1.142	0.574	0.047
Goodman	-3.379	0.995	0.001	-1.142	0.548	0.037
(B) Composition des effets						
Effet indirect (Sobel)	-3.379	0.991	0.001	-1.142	0.561	0.042
Effet direct	-1.313	1.407	0.001	-2.574	1.268	0.042
Effet total	-4.692	1.151	0.000	-3.716	1.199	0.042
% de l'effet total médié		0.720			0.307	

5- Conclusion

Over the years, the exposure of economies to external risks such as the Covid-19 health crisis has demonstrated the importance of technological innovation, primarily the digitalisation of financial systems as an essential instrument for sustainable development, the sustainability of economies, and the reduction of inequalities between men and women. Despite the increase in the penetration rate of fintech, women still lag behind men in terms of digital financial inclusion, especially since they constitute the most vulnerable segment of the population to climate change. Despite the abundant literature on the determinants of women's digital financial inclusion, very little is known about the role of climate vulnerability, and studies analysing the channels through which the relationship evolves are rare. This study fills these gaps by analysing the effect of climate vulnerability on women's digital financial inclusion while focusing on the channels through which the relationship is transmitted at the global level.

Using the ordinary least squares method and various robustness analyses on a sample of 140 countries from 2014 to 2021, it emerges that climate vulnerability reduces digital financial inclusion among women. Furthermore, the mediation analysis shows that this negative effect is influenced by the level of economic development (70%) and remittances from migrants (30%), on average. This study contributes to the literature on women's digital financial inclusion by identifying one of the main obstacles to achieving Sustainable Development Goal 5. It highlights the need for governments to recognise the negative implications of climate vulnerability on women's financial empowerment.

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Annexes

Table A1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Account at the bank	140	3.848	.763	.513	5.699
Digital payment	140	3.621	.844	.405	4.603
Saved at a financial institution or MBA	115	2.888	1.123	-2.04	4.429
Borrowed money from a formal institution or MBA	115	2.877	.872	-.274	4.397
Vulnerability	137	.419	.089	.261	.634
Education attainment secondary	125	3.632	.858	.722	4.578
Unemployment	139	1.808	.737	-.892	3.224
Proportion of seats held by women	138	3.015	.71	-2.201	4.128
Women Business and Law Index score	140	4.312	.27	3.291	4.605
Urban population	139	15.943	1.468	12.933	20.515
pop den1500	90	.477	1.509	-3.831	4.61
Ethnic fragmentation	138	.432	.263	0	.908
Linguistic fragmentation	138	.385	.294	0	.904
Religious fragmentation	138	.414	.244	0	.86
Distance from the equator	91	.37	.385	0	1.72
Total natural resources	140	6.558	9.071	0	45.365
Political stability	140	-.235	.935	-2.727	1.475
GDP	139	8.614	1.443	5.647	11.587
Remittances	135	.404	1.744	-4.253	3.454

Table A2: List of countries

Afghanistan	Burundi	Estonia	Ireland	Malawi	North Macedonia	South Sudan
Albania	Cambodia	Ethiopia	Israel	Malaysia	Norway	Spain
Algeria	Cameroon	Finland	Italy	Mali	Pakistan	Sri Lanka
Angola	Canada	France	Jamaica	Malta	Panama	Sudan
Argentina	Central African Republic	Gabon	Japan	Mauritania	Paraguay	Sweden
Armenia	Chile	Gambia, The	Jordan	Mauritius	Peru	Switzerland
Australia	China	Georgia	Kazakhstan	Mexico	Philippines	Tanzania
Austria	Colombia	Germany	Kenya	Moldova	Poland	Thailand
Azerbaijan	Congo, Dem. Rep.	Ghana	Korea, Rep.	Mongolia	Portugal	Togo
Bahrain	Congo, Rep.	Greece	Kosovo	Montenegro	Romania	Tunisia
Bangladesh	Costa Rica	Guatemala	Kuwait	Morocco	Russian Federation	Turkiye
Belarus	Cote d'Ivoire	Guinea	Kyrgyz Republic	Mozambique	Rwanda	Ukraine

Belgium	Croatia	Haiti	Lao PDR	Myanmar	Saudi Arabia	United Kingdom
Benin	Cyprus	Honduras	Latvia	Namibia	Senegal	United States
Bolivia	Czechia	Hong Kong SAR, China	Lesotho	Nepal	Serbia	Uzbekistan
Bosnia and Herzegovina	Denmark	Hungary	Liberia	Netherlands	Sierra Leone	Venezuela, RB
Botswana	Dominican Republic	India	Libya	New Zealand	Singapore	Viet Nam
Brazil	Ecuador	Indonesia	Lithuania	Nicaragua	Slovak Republic	Yemen, Rep.
Bulgaria	Egypt, Arab Rep.	Iran, Islamic Rep.	Luxembourg	Niger	Slovenia	Zambia
Burkina Faso	El Salvador	Iraq	Madagascar	Nigeria	South Africa	Zimbabwe