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Abstract

Purpose – The role of renewable energy is increasingly seen as a means of promoting women's economic participation and improving their health by rebalancing climate degradation.

Design/methodology/approach – To shed light on this relationship, we assess the capacity of renewable energy to reduce the negative impact of climate vulnerability on women's economic empowerment and health, using the GMM estimator for 36 African countries over the period 1990-2021.

Findings – The empirical results show that: (i) climate vulnerability reduces economic empowerment and (ii) climate vulnerability increases child mortality. These results are mitigated by the use of renewable energy. (iii) The use of renewable energy mitigates the negative impact of climate vulnerability on women's economic empowerment. (iv) Renewable energy use also reduces the pressure of climate vulnerability on child mortality. In addition, we take into account regional heterogeneities and find distinct effects. Our results remain stable after further robustness testing.

Originality/value – Renewable energy thresholds are provided at which climate vulnerability no longer reduces women’s socio-economic wellbeing.

Keywords: Renewable energy, climate vulnerability, women's economic empowerment, women's health, infant mortality and Africa

1.Introduction

The causality between climate vulnerability and women's socio-economic well-being is a topic of interest to economists and public authorities because of its importance and topicality (Asaduzzaman, 2015). However, according to the Care Canada report (2010), around two-thirds of women worldwide are exposed to climate shocks. Statistics on the victims of climate-related disasters clearly show that women are more at risk than men. For example, the 1991 floods and cyclones in Bangladesh showed that 90% of victims were women. In 2004, 75% of the victims of the Aceh disaster were women. Furthermore, according to Gaalya (2015), 61% of the victims of Cyclone Nargis in Myanmar in 2008 were women. This result is correlated with women's economic under-representation and women's human under-development. According to Goh (2012), climate vulnerability affects all aspects of human life, directly and indirectly, and more specifically women's economic well-being. The work of Aguilar (2007) and Ergas and York (2012) shows that climate change vulnerability increases women's economic inequality 14 times more than men.

Moreover, according to the World Health Organization (WHO) and the American College of Obstetrics and Gynecologists (2016), climate change affects women's health through a multitude of mechanisms, including heat, poor air quality, extreme weather events, as well as weather changes that alter vector-borne diseases, reduce water quality and decrease food security (Crimmins et al., 2016; Chauhan and Kumar, 2016). Women's health vulnerabilities are further compounded by poverty, which amplifies the risks at regional level. Globally, 1.3 billion people live below the poverty line in low- and middle-income countries, 70% of whom are women (WHO, 2020).

Furthermore, the climate literature points out that increasing the use of clean energy can reduce carbon emissions by between 7% and 41% in Iran (Mostafaeipour et al., 2022). Similarly, a large body of research shows that increasing renewable energy consumption encourages a reduction in carbon emissions in the United States (Jaforullah and King, 2015), China (Liu et al., 2015), 25 African countries (Zoundi, 2017) and 17 OECD countries (Bilgili et al., 2016). As a result, it promotes women's economic and social well-being (Yadav and Lal, 2018). According to Surya et al. (2021), renewable energy offers opportunities for economic empowerment, climate change resilience and improved living conditions for women. In addition, Santika et al. (2019), Daher-Nashif and Bawadi, (2020) point out that the use of cleaner household energy contributes to improving women's health. Moreover, Krishnapriya et al. (2021), show that the use of clean energy in households reduces the cost of time spent by women on tasks such as cooking, and women get more rest and suffer fewer physical ailments.

In the light of the above and Section 2, there is a sparse literature focusing on how renewable energy can be employed to moderate the negative impact of climate vulnerability on women's economic empowerment and health. Furthermore, while the underlying studies have focused on direct linkages between renewable energy and climate vulnerability on the one hand and on the other, the nexus between climate vulnerability and the socio-economic wellbeing of women, in the present study, we argue that policy makers and scholars can be better informed if studies provide actionable levels of renewable energy that can be used to mitigate the unfavorable effect of climate change on the socio-economic wellbeing of women. In essence, while it is relevant for policy makers to understand whether climate vulnerability affects the socio-economic wellbeing of women negatively or positively, it is even more policy-relevant if corresponding policy makers are provided with thresholds of renewable energy that national policies must endeavour to reach in order for climate vulnerability to no longer represent an impediment to the socio-economic wellbeing of the women.

Building on the above, the objective of this empirical paper is to study the effect of renewable energy on reducing climate vulnerability that threatens the socio-economic well-being of women in 36 African countries. Accordingly, the contributions of this paper are: (i) to show that the use of a linear relationship to study the relationship between renewable energy and women's economic empowerment on the one hand and women's health on the other hand is not relevant, we propose a non-linear form based on the quadratic function to determine, on the one hand, whether the relationship is concave (with a maximum) or convex (with a minimum) and, on the other hand, to study the interaction between the use of renewable energy and climate vulnerability. (ii) We also attempt to determine at what threshold the renewable energy is a variable favourable to women's economic empowerment or human development (women's health).

The remainder of this paper is structured as follows. The second section presents the literature review, the third section describes the methodology, the data and empirical results are covered in the fourth section while the fifth section draws the main conclusions and policy implications.

2.Literature review

2.1 Renewable energy, climate vulnerability and women's empowerment

Climate vulnerability is a threat facing humanity today. Women in particular are the first victims of the adverse effects of climate change because of their role in caring for the family and their responsibilities for gathering fodder, firewood and water (Nellemann et al., 2011; Nwoke and Ibe, 2014). In essence, caring for the family necessities some activities that are negatively affected by climate change, *inter alia*, less forest needed for firewood and less water owing to droughts for instance. Nevertheless, women are also effective agents of change, as they often cope with and adapt to climate change differently from men using their particular knowledge and livelihood strategies (Israel and Sachs, 2013). Indeed, existing studies (Semeraro et al., 2018; Flores and Peralta, 2020; Lammers et al., 2024) highlight that women's reliable access to renewable energy infrastructure plays a key role in climate change adaptation and increases their resilience to natural disasters, not least, because reliance on renewable energy is associated with less activities that are linked to climate change such as deforestation for heating and energy. Similarly, access to renewable energy increases women's financial autonomy and bargaining power by reducing the time spent on household chores and increasing women's time and presence in gainful employment (Dinkelman, 2011; Grogan and Sadanand, 2013).

Access to clean energy at household or community level can help women to engage in less polluting activities (e.g., less use of firewood) in both households and the communities. For instance, using less firewood for cooking and heating is associated with less deforestation. More generally, access to clean, affordable energy can help women to emancipate and overcome patriarchal structures that increase their vulnerability to climate change and which can even cost them their lives in the event of a disaster. Access to clean, affordable energy improves girls' and women's access to education, control over assets, ownership of assets and confidence (McCollum et al. 2018; Allen and Stephens 2019; Das et al., 2020).

2.2 Renewable energy, climate vulnerability and women's health

The literature indicates that women's health is at greater risk (particularly during pregnancy) due to vulnerability to climate change (Duncan, 2006; Levy and Patts, 2015; Sorensen et al., 2018). There is a complex relationship between climate change and women's health, which is underpinned by the existing problem of gender inequality (Sorensen et al., 2018). The difficult lives of women in arid and semi-arid countries are becoming increasingly more arduous than those of men due to greater poverty, lower levels of education and training, more limited access to institutional support and information, and less participation in decision-making bodies (Goh, 2012).

However, women often face unequal access to clean energy resources to cope with climate change (Jerneck, 2018). Consequently, this negatively affects the health of women and children in rural areas (Bourne, 2015). According to Churchill (2021), prolonged household use of unclean energy sources such as firewood can have adverse consequences for women's health. Conversely, the improvement of women's health and the use of cleaner household energy have become important aspects of the Sustainable Development Goals (SDGs) and have a positive correlation (Santika et al., 2019; Daher-Nashif and Bawadi, 2020). According to Wang et al. (2019), it was observed that clean energy consumption in China continued to increase between 2000 and 2014, while maternal mortality decreased, highlighting a significant negative correlation between clean household energy and maternal mortality.

Building on the underlying literature as well as the motivation articulated in the introduction, the following main hypothesis is tested in the empirical section of the study.

Hypothesis 1: renewable energy reduces the negative impact of climate vulnerability on women's economic empowerment and health.

3.Data and methodological approach

3.1 Data

Based on the above assumptions, we empirically demonstrate how renewable energies can be used to reduce the impact of climate vulnerability on women's economic participation and health using the SYS-GMM estimator for all 36 African countries over the full period from 1990 to 2021[1]. We therefore consider two specifications: (i) to analyse the influence of the climate vulnerability indicator and the use of renewable energy, among other control variables, on women's economic participation; and (ii) to analyse the effects of climate vulnerability and

[1] Algeria, Angola, Botswana, Burundi, Cameroon, Djibouti, Gabon, Equatorial Guinea, DRC, Congo, Burkina-Faso, Côte d'Ivoire, Egypt, Eritrea, Ethiopia, Gambia, Ghana, Kenya, Liberia, Libya, Malawi, Mali, Mauritania, Morocco, Mozambique, Niger, Uganda, Senegal, Sierra Leone, Sudan, Lesotho, South Africa, Tanzania, Chad, Zambia and Zimbabwe.

the use of renewable energy, among other control variables, on women's health. The data used come from the World Development Indicators (WDI), Nostradamu, the World Health Organization (WHO) and the International Energy Agency (EIA). The definitions and sources of variables are provided in Appendix Table A1 while the corresponding summary statistics is disclosed in Appendix Table A2. The related matrix is provided in Appendix Table A3.

Looking at Appendix Table A2 pertaining to the summary statistics, it is apparent that women's economic empowerment has an average of 41.952. This low figure is accompanied by little variability between countries. The corresponding standard deviation is 9.324. Considerable efforts seem to have been made with regard to energy consumption, with an average level of 59.919 and a standard deviation of 30.122.

3.2 Methodological approach

Based on earlier work by Asongu et al (2022), we include renewable energy as an additional determinant of women's economic empowerment. Thus, the specifications of the proposed model can be described by the following elements of equation (1):

$$WE_{it} = \propto_1 + \propto_2 VCC_{it} + \sum_{m=1}^{k} \delta m x m_{it} + \mu_{it} + V_{it} + \varepsilon_{it} \quad (1)$$

where *WE* is women's economic empowerment, *VCC* is the climate vulnerability indicator, X is the vector of control variables included in the function, (i.e., Female population density, GDP_per capita, FDI and internet access), V_{it} , andμ_{it} are, respectively, the time-specific constant and the country-specific effect. We expect negative and positive effects of renewable energy and climate vulnerability on women's economic empowerment, respectively.

The empirical analysis also validates the second hypothesis proposed in the previous section. In particular, we consider renewable energies as a conditional variable that moderates the negative effects of climate vulnerability on women's health. As indicated in Section 2, the basic model is structured by including renewable energies, climate vulnerability and their interactive term as independent variables on the right-hand side, as well as five control variables. Consequently, the specification of our second suggested model is presented as follows in Equation (2):

$$HW_{it} = \propto_1 + \propto_2 VCC_{it} + \sum_{m=1}^{k} \delta m x m_{it} + \mu_{it} + V_{it} + \varepsilon_{it} \ (2)$$

Where HW denotes women's health; X is the other control variable included in the function, namely: female population density, GDP per capita, FDI and internet access. As equation (2) shows, we expect positive impacts from climate vulnerability and women's health as measured by infant mortality.

Since women's economic empowerment and women's health are dynamic processes with high inertia in their past values, it is important to take this inertia into account. We therefore introduce the lagged value of the index of women's economic empowerment and women's health respectively into Equations (1) and (2) to obtain Equations (3) and (4) below:

$$WE_{it} = \propto_1 + \propto_2 WE_{it-1} + \propto_3 VCC_{it} + \sum_{m=1}^{k} \delta m x m_{it} + \mu_{it} + V_{it} + \varepsilon_{it} \quad (3)$$

&

$$HW_{it} = \propto_1 + \propto_2 HW_{it-1} + \propto_3 VCC_{it} + \sum_{m=1}^{k} \delta m x m_{it} + \mu_{it} + V_{it} + \varepsilon_{it} \quad (4)$$

The analysis of the baseline results is divided into two main tables. Table 1 presents the key results obtained from ordinary least squares (OLS), while Table 2 focuses on the results derived from the system GMM method. The application of these methods allows for the resolution of various econometric issues. First, the preliminary results of the relationship are derived from OLS. Although this approach is interesting, it has the drawback of not correcting for endogeneity. Theoretically, endogeneity problems may arise in this model due to simultaneity, omitted variable bias, measurement errors, or selection bias. An inverse causality may exist between climate vulnerability and the economic empowerment of women as well as women's health. Furthermore, a simultaneity bias may occur because several variables in the model are determined simultaneously.

To address this bias, an appropriate identification strategy is necessary, particularly the generalized method of moments (GMM) technique proposed by Arellano and Bond (1991). GMM is chosen for several reasons. First, we leverage the fact that the individual dimension is more significant than the temporal dimension in our panel data. Second, this method helps resolve the endogeneity issues present in panel data regression. In this study, endogeneity may arise from measurement errors, omitted variables, and reverse causality. Regarding measurement errors, variables related to climate vulnerability, the economic empowerment of women, and women's health are often subject to such errors. This is due to the lack of consensual measures for these variables in the literature.

Concerning omitted variables, some important variables may not be included in the model. Although several determinants of the economic empowerment of women and women's health are crucial, these omitted variables may be correlated with other variables in the model. Finally, the issue of reverse causality may be linked to the fact that climate vulnerability influences the economic empowerment of women and women's health. Additionally, since the economic empowerment of women and women's health depend on their past evolution, including the lagged variable of this empowerment in the model underscores the importance of examining its memory effect (Teng and Lo, 2019). For all these reasons, GMM is the most appropriate method for our study. The consistency of the GMM estimator depends on two factors: the validity of the assumption that the error term does not exhibit serial correlation (AR (2)) and the validity of the instruments (Hansen test). An excessive number of instruments can weaken and bias the Hansen test on identification restrictions, so the general rule is that the number of instruments should be less than the number of countries (Roodman, 2009; Tchamyou and Asongu, 2017).

4.Empirical Analysis

4.1 Presentation of results

Table (1) shows two specifications derived from OLS estimates. Specification (1) highlights the bivariate results of the effect of climate vulnerability on women's economic empowerment. The results show that climate vulnerability affects women's economic empowerment negatively and significantly at the 1% significance level. These results can be explained by the fact that when resources become scarce due to climate change, women are forced to travel longer distances to obtain water, firewood or other necessities. This increases their workload, reducing the time and energy available to participate in productive economic activities (Chidakwa et al., 2020; Md et al., 2022).

Indeed, these results are in line with a strand of extant studies (Abate et al., 2020; Ahmad et al., 2022; Singh et al., 2022), which points out that climate change, such as prolonged droughts or extreme weather events, can affect the availability of natural resources such as water and arable land. Women, who are often responsible for managing natural resources in many societies, are directly affected by these changes, limiting their access to traditional economic livelihoods. Similarly, Glazebrook et al. (2020) and Bue et al. (2022) argue that in many parts of the world, women are over-represented in the informal sector of the economy, particularly in subsistence agriculture. Climate disruptions can lead to crop losses, forced displacement or destruction of infrastructure, affecting women’s ability to maintain their informal livelihoods (Oyilieze et al., 2022).

Following the evidence of the literature, we retain the following control variables: GDP per capita growth, fertility, FDI, female population and internet access (Salahuddin et al., 2020 and Kazemzadeh et al., 2023). The control variables are introduced progressively into the model. The analysis of the control variables focuses essentially on the results contained in Columns (3 to 6). Growth in GDP per capita positively affects the indicator of women's economic participation by around 1%. This corroborates the results of Jonson (2015) and Anyanwu (2016) who show that growth in GDP per capita increases gender equality in women's employment. The same is true for female population density as a percentage of the total population and female economic participation of at least 1%. In an African context, it is possible that a higher proportion of women in the population increases the visibility of women in the workforce. We also observe the positive effects of FDI and inward investment on women's participation in the labor market. This corroborates the work of Klasen and Pieters (2012).

Special feature (2) highlights the bivariate results of the effect of climate vulnerability on infant mortality, and the results show that climate vulnerability has a positive and significant effect of around 1% on infant mortality. This can be explained by the fact that climate change can influence the distribution of disease vectors such as malaria and dengue mosquitoes, as well as water-borne diseases such as diarrhea. Extreme weather conditions can also disrupt drinking water supply and sanitation systems, increasing the risk of infectious diseases in infants and women.

Table 1 : Linear regression with multiple fixed effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	Women's empowerment						Infant mortality					
Climatic vulnerability	-0.499***	-0.348***	-0.318***	-0.187***	-0.187***	-0.286***	0.583***	0.598***	0.526***	0.336***	0.338***	0.361***
	(0.053)	(0.048)	(0.047)	(0.062)	(0.061)	(0.062)	(0.070)	(0.073)	(0.071)	(0.089)	(0.089)	(0.093)
gdp_per capita		-0.015	-0.021	-0.009	-0.012	-0.009		-0.124***	-0.139***	-0.121***	-0.122***	-0.125***
		(0.030)	(0.030)	(0.028)	(0.028)	(0.028)		(0.046)	(0.044)	(0.040)	(0.041)	(0.042)
Women's population			1.433***	1.738***	1.763***	1.854***			3.458***	3.916***	3.950***	3.998***
			(0.278)	(0.264)	(0.263)	(0.257)			(0.419)	(0.382)	(0.382)	(0.384)
Fertility				-0.308***	-0.307***	-0.306***				0.528***	0.528***	0.527***
				(0.026)	(0.026)	(0.025)				(0.037)	(0.037)	(0.037)
FDI					0.114***	0.116***					-0.123**	-0.122**
					(0.040)	(0.039)					(0.058)	(0.058)
Internet						0.084***						-0.015
						(0.018)						(0.026)
Constant	0.167***	0.250***	-0.458***	-0.502***	-0.511***	-0.497***	-0.014	-0.017	-1.727***	-1.770***	-1.782***	-1.793***
	(0.027)	(0.024)	(0.140)	(0.132)	(0.132)	(0.129)	(0.036)	(0.037)	(0.210)	(0.191)	(0.191)	(0.192)
Observations	986	910	948	978	976	965	924	978	978	978	976	965
R-squared	0.547	0.626	0.636	0.686	0.690	0.706	0.512	0.521	0.553	0.632	0.633	0.631
F-statistics	1543***	1002.66***	958***	987.66***	993.9***	993***	707.67***	271.54***	592.72***	1224.98***	493.1***	525.5***

Source: Authors: ***-significant at 1% **- significant at 5% *-significant at 10% robust standard deviations are in brackets.

The OLS estimate is less robust, not least because it fails to account for some dimensions of endogeneity such the unobserved heterogeneity and simultaneity. The coefficients have the highest values in the GMM-SYS estimates compared to the OLS. This justifies the presence of endogeneity and therefore the use of GMM. In table (2), the coefficients of the lagged dependent variables are relatively large and highly significant at the 1 per cent level. This suggests that both women's economic empowerment and child mortality exhibit strong persistence over time, and therefore that past levels are strongly associated with current levels.

More specifically, women in countries where climate change is more frequent often face greater vulnerability to the impacts of climate change due to socio-economic factors. They are more likely to depend on natural resources for their livelihoods, making them more vulnerable to droughts, floods and other extreme weather events (Glazebrook et al., 2020). In addition, women who depend on natural resources for their livelihoods may be exposed to health risks related to pollution and environmental degradation (Oyilieze et al., 2022).

Table 2 : SYS-GMM

	(1)	(2)	(3)	(4)
Variables	Women's empowerment (WE)		Infant mortality	
L.WE	0.988***	0.986***		
	(0.001)	(0.002)		
L. Infant mortality			0.976***	0.973***
			(0.006)	(0.008)
Climate vulnerability	-0.003**	-0.013***	0.021**	0.103***
	(0.001)	(0.001)	(0.008)	(0.008)
gdp_perc		-0.002		-0.260***
		(0.002)		(0.020)
Female population		0.096***		0.610***
		(0.019)		(0.073)
Fertility		-0.007***		0.066***
		(0.002)		(0.003)
FDI		0.012***		-0.031***
		(0.002)		(0.005)
Internet		0.003**		0.022***
		(0.001)		(0.005)
Constant	0.004***	-0.044***	-0.006	-0.278***
	(0.000)	(0.010)	(0.004)	(0.036)
Observations	949	937	992	937
Number of groups	32	32	32	32
Instruments	23	23	18	23
AR (1) p-value	0.0256	0.0307	0.050	0.0970
AR(2) p-value	0.155	0.121	0.220	0.114
Hansen p-value	0.476	0.379	0.131	0.156
Fisher	259.8***	493.1***	499.2***	525.5***

Source: Authors: ***-significant at 1% **- significant at 5% *-significant at 10% robust standard deviations are in brackets.

4.2Robustness analysis: Alternative control of endogeneity

We adopt an instrumental variable approach to account for the simultaneity dimension of endogeneity or reverse causality. To instrument advanced technologies correctly, we need a variable that is correlated with advanced technologies but not with productive capacity, except through the included regression variables (Baum et al., 2007a, 2007b). To overcome this endogeneity problem in the absence of a purely external instrument in our relationship, we will refer to the internal instrumentation approach developed by Lewbel, (2012). We will use the two-stage least squares (2SLS) estimation method of Lewbel (2012). Indeed, we justify the use of Lewbel's 2SLS method by the fact that, unlike other techniques, in particular the instrumental variables technique, finding adequate instruments that can satisfy all the conditions is often very difficult and constitutes a real challenge or even a real problem for most applied research using this instrumental variables technique (Baum et al., 2012; Stock et al., 2002); Lewbel's 2SLS method, which is applied when the sources of identification, in particular having adequate internal and external instruments, are not available or are weak.

In addition, this method is essential for identifying structural parameters in regression models with an endogenous or poorly measured regressor in the absence of traditional identification information. This Lewbel 2SLS approach has instruments that are built in-house based on heteroskedasticity. These internally constructed instruments are generated from the residuals of the auxiliary equation, which are multiplied by each of the included exogenous variables in mean-centred form. In addition, one of the advantages of this approach is that it does not depend on the satisfaction of standard exclusion restrictions (Ngounou et al, 2023). The results of the 2SLS regression are presented in Table (3). The results concerning the quality of the instruments are satisfactory. With regard to the relevance of the instruments, the Kleibergen-Paap Wald rk F statistic is used to test the weakness of the instruments (Kleibergen and Paap, 2006). The Kleibergen-Paap Wald rk F-statistic must be at least 10 for weak identification not to be considered a problem (Saadi, 2020). The statistics presented in Table (3) are greater than 10, indicating that there is no weak identification problem. In addition, the Kleibergen-Paaprk LM statistic is used to test for under-identification. Second, the Sanderson and Windmeijer (2016) F-test value for the excluded instrument is.

Although there is reason to suspect non-orthogonality between regressors and errors, the use of IV estimation to solve this problem must be weighed against the inevitable loss of efficiency compared with OLS. It is therefore very useful to have a test to determine whether OLS is inconsistent and whether it is necessary to use IV or GMM. It is therefore very useful to have a test to determine whether OLS is inconsistent and whether it is necessary to use IV or GMM. Many studies indicate that the climate vulnerability variable may be endogenous. These studies examine the endogeneity of climate vulnerability using the Durbin-Wu-Hausman (DWH) test (Burnside and Dollar 2000; Dalgaard and Hansen, 2001). In line with this literature, the DWH test presented in Table (3) does not reject the null hypothesis of exogeneity of climate vulnerability with respect to women's economic empowerment and child mortality, IV estimation is not required and OLS estimates are unbiased and reliable (Baum et al., 2007a). However, the coefficient associated with climate vulnerability remains statistically significant, which is consistent with our hypothesis.

Table 3 : IV-2SLS LEWBEL

	(1)	(2)	(3)	(4)	(5)	(6)
	IV-2SLS	IV-2SLS LIML	IV-2SLS GMM2S	IV-2SLS	IV-2SLS LIML	IV-2SLS GMM2S
Variables	Women's empowerment			Infant mortality		
Climate vulnerability	-3.564***	-4.739***	-4.065***	2.024***	2.704***	1.910***
	(0.591)	(1.133)	(0.561)	(0.545)	(0.865)	(0.500)
gdp_perc	-0.060	-0.081	-0.089	-0.143*	-0.155*	-0.098
	(0.063)	(0.083)	(0.062)	(0.086)	(0.089)	(0.070)
Female population	-0.318	-2.034	-0.976	3.869***	2.877**	3.909***
	(1.015)	(1.797)	(0.978)	(0.937)	(1.386)	(0.884)
fertility	-0.967***	-1.395***	-1.146***	-0.394**	-0.642**	-0.353*
	(0.215)	(0.412)	(0.204)	(0.200)	(0.316)	(0.184)
FDI	0.264**	0.375**	0.316***	-0.298***	-0.362***	-0.280***
	(0.122)	(0.169)	(0.120)	(0.088)	(0.116)	(0.085)
Internet	-0.058*	-0.091*	-0.067**	-0.148***	-0.167***	-0.148***
	(0.033)	(0.049)	(0.032)	(0.030)	(0.039)	(0.029)
Constant	-0.751**	-0.272	-0.584*	-2.484***	-2.207***	-2.469***
	(0.350)	(0.570)	(0.342)	(0.327)	(0.447)	(0.314)
Observations	965	965	965	965	965	965
R-squared	0.445	0.635	0.722	0.562	0.479	0.453
Kleibergen-Paap rk LM p-value	0.000	0.000	0.000	0.000	0.000	0.000
Endogeneity test	0.020	0.023	0.017	0.019	0.080	0.071
Hansen J-test	0.616	0.406	0.832	0. 601	0.931	0.320
Kleibergen-Paap rk	16.428	16.428	16.428	16.428	16.428	16.428

Source: Authors: ***-significant at 1% **- significant at 5% *-significant at 10% robust standard deviations are in brackets.

4.3 Sensitivity analysis: Regional heterogeneity

We also seek to verify whether the baseline estimation results vary according to the sub-regions of Africa. To do this, we estimate by sub-region. The results are shown in Table 4 below.

Analysis of Table 4 shows that climate vulnerability is negatively related to economic empowerment in the different regions of Africa. Moreover, the effect is greater in the West Africa sub-region, which is justified by the fact that this is the sub-region with the highest level of climate vulnerability and women in this region are disadvantaged because most are engaged in informal activities such as agriculture. This is followed by South Africa, North Africa and East Africa. In Central Africa, on the other hand, these facts are not significant, which is justified by the fact that this region is less vulnerable to the climate. This result is in line with that of Oyilieze et al. (2022).

As far as infant mortality is concerned, the results differ from one African region to another, with the greatest effect being seen in southern African countries, followed by northern Africa. This is justified by the fact that this is the sub-region most affected by climate change. In other regions, however, the effect is less significant. This result is in line with that of Glazebrook et al. (2020).

Table 4 : Heterogeneity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Eastern Africa	Central Africa	Northern Africa	Southern Africa	Western Africa	Eastern Africa	Central Africa	Northern Africa	Southern Africa	Western Africa
Variables	Women's empowerment					Infant mortality				
Climate vulnerability	-0.481***	-0.031	-0.822***	-1.001***	-1.261***	0.310	0.167	1.242***	4.820**	0.353
	(0.037)	(0.480)	(0.274)	(0.344)	(0.260)	(0.308)	(1.316)	(0.321)	(2.278)	(0.298)
gdp_perc	0.007	0.023	0.001	-0.031	0.029	-0.360***	0.068	-0.005	0.034	-0.009
	(0.008)	(0.019)	(0.007)	(0.030)	(0.028)	(0.068)	(0.053)	(0.008)	(0.195)	(0.032)
Female population	1.573***	-2.280***	0.469	0.219	1.528***	4.310***	3.849***	3.961***	5.875***	-0.117
	(0.154)	(0.315)	(0.288)	(0.285)	(0.506)	(1.284)	(0.866)	(0.337)	(1.884)	(0.580)
Fertility	-0.019	-0.074	0.320***	-0.001	0.018	-0.065	-0.532*	0.175***	2.141***	0.372***
	(0.013)	(0.100)	(0.051)	(0.096)	(0.064)	(0.110)	(0.274)	(0.059)	(0.632)	(0.073)
FDI	0.066***	-0.012	0.091	-0.034	-0.051	0.201*	-0.057**	-0.176**	-0.007	-0.118***
	(0.013)	(0.010)	(0.070)	(0.039)	(0.034)	(0.106)	(0.027)	(0.082)	(0.255)	(0.039)
Internet	0.082***	- 0.034**	0.054***	0.054***	0.065***	0.107	0.087**	0.025*	0.232**	0.021
	(0.009)	(0.015)	(0.013)	(0.016)	(0.024)	(0.074)	(0.042)	(0.015)	(0.108)	(0.027)
Constant	-0.591***	1.629***	-0.479***	-0.156	-1.042***	-1.980***	-1.443**	-2.362***	-1.486	-0.080
	(0.084)	(0.254)	(0.156)	(0.162)	(0.256)	(0.703)	(0.697)	(0.182)	(1.072)	(0.294)
Observations	325	83	111	96	350	325	83	111	96	350
F-statistics	43.17***	32.3***	36.5***	34.8***	49.3***	40.21***	29.98***	38.95***	37.38***	52.5***
R-squared	0.983	0.998	0.992	0.924	0.914	0.801	0.984	0.972	0.896	0.906

Source: Authors:***-significant at 1% **- significant at 5% *-significant at 10% robust standard deviations are in brackets.

4.4The role of renewable energy

So far, the results presented examine the direct effects of climate vulnerability on women's economic empowerment and women's health as measured by infant mortality. However, the literature on climate vulnerability recognises the existence of a non-linear relationship between climate vulnerability and development outcomes (Bruno Soares et al., 2012, Islam, 2022 Ndjokou & Asaloko, 2024). We now seek to determine whether countries with greater access to climate resilience systems such as renewable energy benefit more than others. Using the model specified in Equations (5 and 6), we introduce an interaction variable between climate vulnerability and renewable energy. The model then takes the following form:

$$WE_{it} = \alpha_0 + WE_{it-1} + Ren_{it} + VCC_{it} + \gamma X_{it} + \pi_1(VCC * Ren)_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (5)$$

$$HW_{it} = \alpha_0 + HW_{it-1} + Ren_{it} + VCC_{it} + \gamma X_{it} + \pi_1(VCC * Ren)_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (6)$$

Where π is a vector of interaction terms between climate vulnerability and renewable energies. In Table (5), we present climate vulnerability, renewable energy and their interaction on women's political empowerment and women's health. Indeed, the effects of climate vulnerability on women's economic empowerment and women's health are consistent with the previous results.

The coefficient on the renewable energy variable is positive and statistically significant at least at the 1% level. The interaction terms between climate vulnerability and renewable energy are very important for women's economic empowerment. This interaction term shows how the effect of climate vulnerability on women's economic empowerment depends on renewable energy. The estimated coefficient is positive and statistically significant, suggesting that climate vulnerability can increase women's economic empowerment if there is a high level of renewable energy, consistent with extant research (McCollum et al., 2018; Allen and Stephens 2019; Das et al., 2020)

Women's health is measured by infant mortality. The coefficients of the renewable energy variables are negative and statistically significant at least at the 1% level. The interaction terms between climate vulnerability and renewable energy are very important for health. These interaction terms show how the effects of climate vulnerability on women's health depend on renewable energy. The estimated coefficients are negative and statistically significant, suggesting that climate vulnerability can reduce infant mortality if women have access to renewable energy. Women living in more vulnerable countries may benefit from better health if they have access to renewable energy.

Table 5: The moderating role of renewable energies

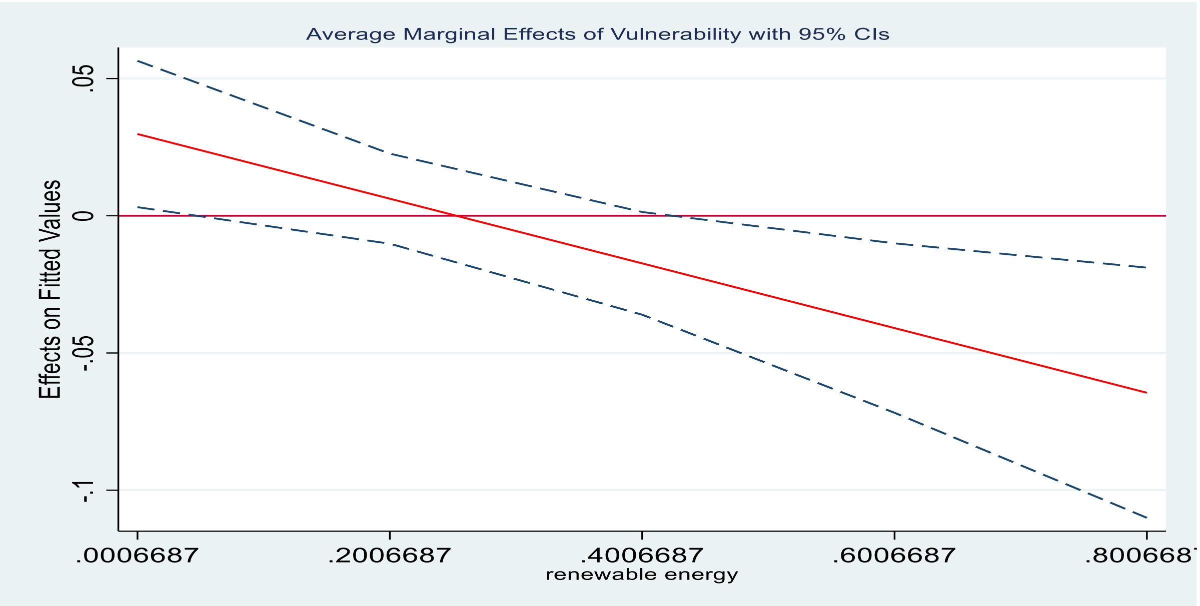
	(1)	(2)
Variables	Women's empowerment	Infant mortality
L. Women's empowerment	0.986***	
	(0.001)	
L. Infant mortality		0.960***
		(0.009)
Climate vulnerability	-0.008***	0.030**
	(0.002)	(0.014)
Enerenew	0.005***	- 0.049**
	(0.001)	(0.021)
Vul#enerenew	0.013***	-0.118***
	(0.003)	(0.041)
gdp_perc	0.002**	-0.217***
	(0.001)	(0.032)
Female population	0.123***	0.246***
	(0.011)	(0.074)
Fertility	-0.001**	0.030**
	(0.001)	(0.013)
FDI	0.005**	0.003
	(0.002)	(0.016)
Internet	-0.001*	-0.022***
	(0.001)	(0.005)
Constant	-0.052***	-0.131***
	(0.006)	(0.041)
Renewable energy threshold	0.615 (+ve threshold)	0.254 (-ve threshold)
Observations	918	918
Number of groups	32	32
Instruments	21	27
AR (1) p-value	0.0374	0.136
AR (2) p-value	0.0848	0.029
Hansen p-value	0.807	0.252
Wald statistics	428.04***	368.93***

Source: Authors: ***-significant at 1% **- significant at 5% *-significant at 10% robust standard deviations are in brackets.

In order to improve room for policy implications, the study is consistent with the extant threshold literature (Asongu and Odhiambo, 2019, 2021) in computing the renewable energy thresholds at which the unconditional unfavorable effect of climate change on women's socio-economic wellbeing changes in sign. For instance, in the first specification of Table 5, when renewable energy reaches a threshold of 0.615 (0.008/0.013) (% of GDP), climate vulnerability no longer has a negative effect on women empowerment. In the same vein, in the second specification of Table 5, when renewable energy reaches a threshold of 0.254 (0.030/0.118) (% of GDP), climate vulnerability no longer has a positive effect on infant mortality. Figure (1) shows these effects graphically. The upper and lower blue dashed lines represent the 95% confidence intervals. The coefficients of the interaction terms between climate vulnerability and renewable energy attenuate the negative effect of climate vulnerability on women's economic empowerment. Thus, the effect of climate vulnerability on women's economic empowerment is conditioned by renewable energy. In other words, better access to renewable energy is by Canel which climate vulnerability positively affects women's economic empowerment.

When the upper and lower limits of the confidence interval are both above or below the zero line, the marginal effects are statistically significant. For example, in the top right graph climate vulnerability has a significant negative effect on women's economic empowerment when renewable energy is below 0. Once renewable energy is above 0 this marginal effect becomes positive. These results further suggest that the effects of climate vulnerability on women's economic empowerment depend on renewable energy.

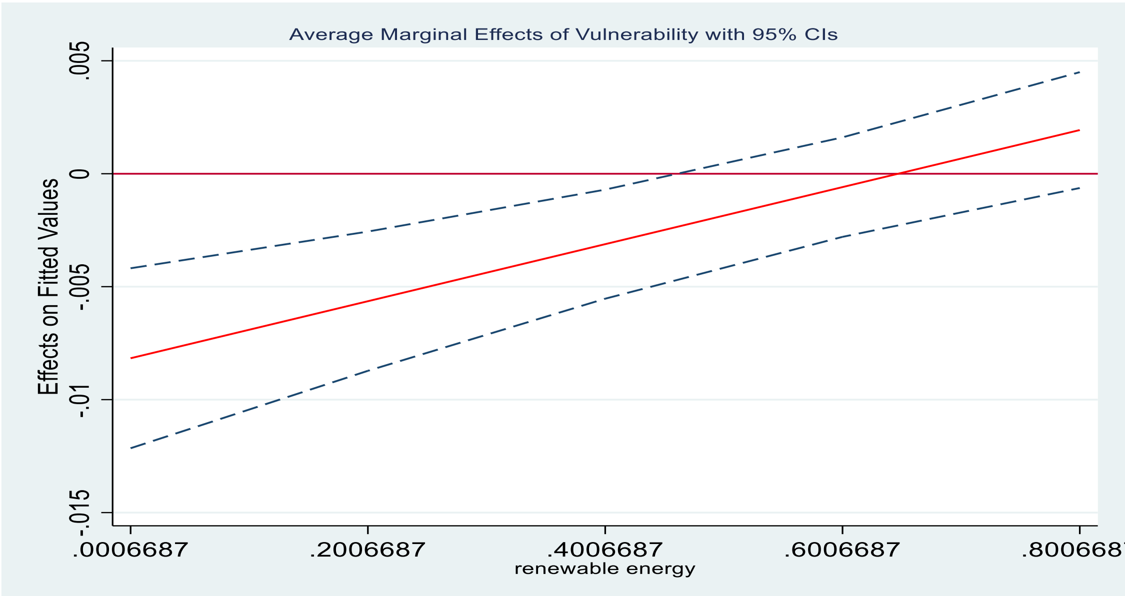
Figure 1: The distribution of conditional marginal effects of access to renewable energy on the relationship between climate vulnerability and women's economic empowerment



Source: Authors

The results in column (1) also show that renewable energy moderates the positive effect of climate vulnerability on children's mortality. The marginal effect obtained in column (2) and plotted in the upper left-hand corner of Figure 2 shows that strong access to renewable energy reduces children's mortality. The relationship between climate vulnerability and child mortality is essentially positive, but only becomes negative for high scores of accesses to renewable energy.

Figure 2: The distribution of conditional marginal effects of access to renewable energy: On the relationship between climate vulnerability and women's health



Source: Authors

5.Conclusion, implications and future research directions

This paper examines the role of renewable energy on the relationship between climate vulnerability and women's economic empowerment, as well as women's health as measured by infant mortality in African countries. The role of renewable energy is increasingly seen as a means of promoting women's economic participation and improving their health by rebalancing climate degradation. To shed light on this relationship, we assess the ability of renewable energy to reduce the negative impact of climate vulnerability on women's economic empowerment and health, using the GMM estimator for 36 African countries over the period 1990-2021. The empirical results show that: (i) climate vulnerability reduces economic empowerment and (ii) climate vulnerability increases child mortality. These results are mitigated by the use of renewable energy. (iii) The use of renewable energy mitigates the negative impact of climate vulnerability on women's economic empowerment and (iv) Renewable energy use also reduces the pressure of climate vulnerability on child mortality. In addition, we take into account regional heterogeneities and find distinct effects. Our results remain stable after further robustness testing.

In order to improve room for policy implications, the study compute the renewable energy thresholds at which the unconditional unfavorable effect of climate change on women socio-economic wellbeing changes in sign. When renewable energy reaches a threshold of 0.615 (% of GDP), climate vulnerability no longer has a negative effect on women empowerment. In the same vein, when renewable energy reaches a threshold of 0.254 (% of GDP), climate vulnerability no longer has a positive effect on infant mortality. As a corresponding policy implication, policy makers should make sure that renewable energy exceeds the corresponding thresholds in order for climate vulnerability to no longer reduce women's socio-economic wellbeing. Reaching the corresponding thresholds require less policy effort because these are closer to the minimum, compared to the maximum of the renewable energy distribution.

The policy recommendations are as follows: (i) Governments should actively promote the adoption of renewable energies such as solar, wind and hydro power. This would reduce dependence on fossil fuels, thereby helping to mitigate climate change. (ii) Public and private funds should be directed towards the development of sustainable energy infrastructure in vulnerable areas. This can create economic opportunities, particularly for women, by promoting job creation in the renewable energy sector. (iii) Training and education programmed should be put in place to enable women to acquire the necessary skills to work in the renewable energy sector. This would promote their economic empowerment by providing employment and career development opportunities. (iv) Initiatives to provide access to clean energy in rural and marginalized communities should be prioritized. This can improve the health and well-being of families by reducing dependence on polluting fuels, which helps to reduce child mortality. (v) Renewable energy policies and programmed should integrate a gender perspective, taking into account the specific needs of women in planning, implementation and evaluation. This can ensure that the socio-economic benefits of renewable energy are realized.

By adopting these policy recommendations, governments can create an environment conducive to the promotion of renewable energies, while fostering the economic empowerment of women and reducing infant mortality, thereby contributing to sustainable and equitable development. The findings can be improved in terms of reconsidering the analytical framework within the remit of other SDGs of the United Nations. For instance, interacting renewable energy with climate vulnerability to assess the overall incidence on SDG 1(i.e., extreme poverty reduction) or SDG10 (i.e., income inequality mitigation) can be considered in future research. Moreover, understanding how the findings withstand empirical scrutiny in other developing regions such as Asia and Latin America is worthy of consideration. Last but not the least, country-specific analyses should be considered in view of providing results with more targeted implications at country levels.

Appendices

Table A1: Presentation and definitions of variables

Variables	Description	Sources
Women's economic empowerment	Employment/population ratio, 15–64-year-olds, women (%) (ILO modeled estimate).	OIT (2023)
Infant mortality	Mortality rate of infants	WHO (2022)
Climate vulnerability	Global climate vulnerability index	Nostradamus (2023)
Fertility	Birth/woman total term	WDI (2023)
FDI	Foreign direct investment measured by net FDI inflows as a percentage of GDP	WDI (2023)
Internet	Internet access and use per capita indicator	WDI (2023)
GDP_per capita	Gross domestic product divided by population at mid-year	WDI (2023)
Female population	The density of the female population	WDI (2023)
Renewable energy	% of total final energy	EIA (2023)

Table A2: **Descriptive Statistics**

Variable	Obs	Mean	Std. Dev.	Min	Max
Women's empowerment	1056	41.952	9.324	12.238	54.1
Mortf	1024	281.62	118.276	61.947	997.597
Fertility	1024	4.718	1.404	1.36	7.365
Climatic vulnerability	1090	0.506	0.062	0.379	0.614
gdp_per capita	1010	1.352	6.141	-47.9	96.956
Women's population	1056	50.447	0.92	46.523	53.082
FDI	1042	2.794	4.509	-10.954	42.093
Internet	1008	10.304	16.936	0.00	88.13
Enerenew	1003	59.919	30.122	0.06	97.45

Table A3 : **Correlation matrix**

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Women's empowerment	1.000								
mortf	0.631	1.000							
fertility	0.506	0.495	1.000						
Climatic vulnerability	-0.598	-0.435	-0.781	1.000					
gdp_per capita	0.014	-0.063	-0.042	-0.012	1.000				
Women's population	0.481	0.530	0.032	0.218	0.028	1.000			
FDI	0.016	-0.070	-0.052	0.038	0.106	0.022	1.000		
internet	-0.269	-0.419	-0.530	-0.375	-0.038	-0.112	0.088	1.000	
enerenew	0.732	0.549	0.807	0.736	-0.026	0.158	-0.013	-0.436	1.000

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