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**Women empowerment and
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Forthcoming: Climatic Change

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Abstract

This study examines whether and how women's socioeconomic empowerment affects environmental quality in African countries using the system Generalised Method of Moments. The empirical findings show that environmental sustainability is associated with the socioeconomic empowerment of women. The result remains robust when controlled for women's political inclusion and female labour force participation. The results equally show that foreign direct investment (FDI) and gross domestic product (GDP) moderate the positive influence of the socioeconomic empowerment of women on greenhouse gas (GHG) emissions. However, some critical levels of per capita GDP and FDI should be reached before these interacting variables effectively moderate the socioeconomic empowerment of women for an overall negative effect on GHG emissions. The study shows that women's empowerment is not only an instrument for environmental outcome, but can be valuable when combined with policies favoring green FDI and economic development in terms of GDP per capita. Policy implications are also discussed in terms of strategies aimed at: (i) attracting FDI that is environmental-friendly and (ii) simultaneously increasing GDP per capita and FDI while ensuring environmental quality.

Key words: Environmental Sustainability, Ecofeminism, Women Empowerment, Thresholds, Net Effects, Sustainable Development.

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1. Introduction

The pursuit of gender parity and the demand for a safe environment have piqued academic curiosity about the fundamental relationship between women's empowerment and environmental preservation. Thus, some of the most important modern issues facing governments worldwide are the empowerment of women and environmental sustainability¹. Several contemporary scholars have cautioned that if policymakers do not harness efforts towards abating gender exclusion, then the global quest for sustainable development may remain futile (Achuo et al., 2024). Hence, environmental sustainability and women empowerment are two entwined contemporary development challenges facing African economies. Women empowerment generally entails raising the standing of women in society on the social, economic, and political fronts (Sinha et al., 2019; Duflo, 2012). In particular, women empowerment consists in creating a favourable socio-political climate that can guarantee the safety of women, allowing them to go about their daily lives without fear of retaliation, abuse, unhappiness, discrimination, or the general sense of harassment that comes with being a woman in a male-dominated world (Ghasemi et al., 2021; Rani, 2017).

The recent United Nations (UN) Sustainable Development Goals (SDGs) place particular emphasis on the importance of women empowerment in driving sustainable development across the globe. For instance, SDG-5 highlights the global resolve to end all forms of violence, discrimination, and harmful practices against women; guarantee equal opportunities and women's full and effective participation in socioeconomic and political decision-making processes; and to implement reforms that grant women equal rights to access economic and financial resources, including land (UN, 2015). Hence, women empowerment is now considered as a veritable driver of socioeconomic development as well as environmental sustainability, as revealed by ecofeminists literature (Jie et al., 2023; Ghasemi et al., 2021; Rao, 2012; Sturgeon, 2009). These ecofeminists studies support the idea that environmental sustainability is positively associated with women's participation in the economic, social and political spheres.

Besides, ensuring a sound and safe environment is crucial in the modern development drive. However, as demonstrated by several SDGs, environmental issues are complex and account for about 20% of the SDGs. For example, the 2015-2030 development agenda in SDG-14 highlights the pledge of world leaders to ensure environmental sustainability by reducing all forms of marine pollution through sustainable use of oceans, seas, and marine resources.

¹ Morelli (2011) defined environmental sustainability as "a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity" (p.5).

Likewise, SDG-15 shows the global desire to increase afforestation, curb deforestation and biodiversity loss, and combat desertification. Environmental concerns are further buttressed in SDG-13 relating to the integration of climate change actions into national development strategies (UN, 2015). Hence, Sturgeon (2009) argued that it is imperative for governments to design policies targeting abatements in greenhouse gas (GHG) emissions as a means of achieving the much-desired environmental sustainability.

Nonetheless, some contemporary studies reveal that existing social and cultural structures have a significant influence on environmental issues (Odey et al., 2022; Hargrove and Sommer, 2022; Danquah et al., 2021). Consistent with ecofeminist theoretical constructs, Gaard (1993) opined that feminist issues can be approached from the standpoint of environmental issues. This hypothesis is authenticated by Ghasemi et al. (2021) who argue that the socioeconomic empowerment of women has a significant impact on environmental conservation. Despite the existence of a few recent studies devoted to the link between environmental degradation and women political empowerment in the context of African economies (Asongu et al., 2021b; Aseidu et al., 2023; Achuo et al., 2025), little remains known with regard to the relation among women's social and economic empowerment and environmental quality. Thus, the question whether female socioeconomic empowerment is environment enhancing or damaging has not been given considerable attention in scholarly literature. Although gender equality and environmental sustainability are among the fundamental contemporary global development challenges, the issue of gender inequality is even more preoccupying within the context of Africa (Langnel et al., 2021; Dogan and Kirikkaleli, 2021; Achuo et al., 2025). Across the African continent, although women play key roles in household energy use and natural resource management, they remain largely marginalised in environmental governance, political and socioeconomic representation (Mete et al., 2025; Aseidu et al., 2023). This disparity indicates that women's potential to foster sustainable solutions is not only underutilised, but that they are disproportionately affected by environmental pollution. However, theoretical underpinnings particularly from feminist political ecology and ecofeminism opine that women empowerment fosters environmental sustainability (Warren and Cheney, 1991). Even though these claims are largely supported by recent empirical studies (Khan, 2023; Rumph et al., 2022), there is evidence of contextual specificities (Achuo et al., 2025).

Thus, the motivation of the current study stems from the rapidly growing body of literature supporting the potential of women empowerment in fostering sustainable practices and enhancing community resilience to climate shocks. Nevertheless, empirical evidence remains disjointed and context-specific, with very limited causal acumens as regards the environmental impacts of specific dimensions of women empowerment. Therefore, this study

makes some remarkable contributions to extant literature. Specifically, besides filling a research gap in ecofeminist literature regarding the direct effects of women's socioeconomic empowerment on pollution emissions, this study disentangles some indirect paths through which women empowerment can affect environmental quality. Moreover, this study uses a more inclusive and appropriate composite indicator² to capture women's socioeconomic empowerment in contrast to previous research that utilizes traditional metrics of women's empowerment (Langnel et al., 2021; Asongu et al., 2021a; Ghasemi et al., 2021).

By unravelling these issues and identifying the economic conditions under which women empowerment promotes environmental sustainability, this study contributes to extant empirical literature on ecofeminism and offers practical guidance for policymakers across Africa with regard to the design of actionable policies that simultaneously protect the environment and promote gender equality.

Consequently, the current study aims to: (1) examine how women's socioeconomic empowerment affects environmental quality in Africa, and (2) identify mediating economic factors (notably FDI inflows and GDP per capita). The key findings from the system GMM estimator show that environmental sustainability is associated with women's socioeconomic empowerment. Furthermore, the results show that FDI inflows and GDP exert moderating effects on the positive environmental impact of women empowerment; thus engendering corresponding positive net effects of 0.0035 and 0.0021, that are nullified upon attainment of threshold values of 9.611 FDI (% of GDP) and 9.514 GDP (annual % growth) by the respective policy moderating variables. The established thresholds are important in informing policymakers on the critical levels of GDP and FDI inflows at which the socioeconomic empowerment of women no longer promote environmental sustainability.

The remainder of the study is structured as follows. Section 2 reviews the literature, while section 3 outlines the research methodology. The findings are presented and discussed in section 4, while section 5 concludes the study.

² The study adopts the World Bank's (2020) composite indicator called, "Women, Business and the Law Index", that was created with the intension to educate policymakers about the tactics that can lessen legal constraints on women and encourage research on the socioeconomic inclusion of women.

2. Literature review

This section provides a critical review of extant theories and empirical literature with regard to the nexus between women empowerment and environmental sustainability.

2.1. Theoretical foundations

Contemporary development studies incorporating the environmental dimension often draw inspiration from the celebrated Environmental Kuznets Curve (EKC) hypothesis, developed by Grossman and Krueger (1995). The EKC hypothesis suggests that environmental degradation increases in the early stages of economic development and decreases when per capita income attains a certain threshold, thereby indicating the existence of an inverted U-shaped relation between economic growth and environmental degradation. Due to the increasing interdependence of world economies, the EKC hypothesis is complemented by two two-trade based theories that link Foreign Direct Investments (FDI) to environmental quality, notably the Pollution Halo and Pollution Haven Hypotheses (Achuo and Ojong, 2025; Ofori et al., 2023). The Pollution Haven hypothesis suggests that environmental degradation in developing countries is associated with dirty FDI inflows from developed countries. This is largely due to relocation of polluting industries from developed countries to developing countries with weak environmental regulations. Conversely, the Pollution Halo hypothesis argues that FDI inflows contribute to enhancing environmental quality. This is contingent on the assumption that multinational companies are likely to afford and use cleaner technologies, adopt better standards and managerial practices that contribute to enhancing environmental preservation.

Given that these baseline environment-oriented development theories do not include the gender component, and that the current study is largely focused on integrating the gender component in environmental studies within the context of Africa, there is need to explore complementary theoretical lenses that associate environmental pollution to gender inequality. In this light, the underlying interconnections between women empowerment and environmental sustainability rely essentially on two fundamental theories notably ecofeminism and feminist political ecology. Proponents of ecofeminism (Sturgeon, 2009; Rao, 2012) opine that uneven power relations and values that are characteristic of male-controlled structures that dominate women entail gender inequality which in turn lead to environmental degradation. However, while Sturgeon (2009) considers ecofeminism as any political practice and theory that links women empowerment to environmental issues, Rao (2012) sees ecofeminism as a "value system, a social movement, and a practice" that can provide a political analysis highlighting the association between androcentrism and environmental pollution.

Likewise, feminist political ecology, which is an extension of ecofeminism tenets stresses how gendered access and control of natural resources interconnects with politics and the environment. Explicitly, proponents of feminist political ecology opine that environmental degradation and the subjugation of women are linked and are products of capitalism and patriarchal structures (Warren and Cheney, 1991). The theory investigates the interconnections between gender, power, and environmental challenges, in particular social and ecological situations. This demonstrates that gender inequality be it economic, political or social which are rooted in capitalist structures systematically lead to environmental degradation. Implicitly, curbing economic gender inequality will enhance the fight for climate change and reduce environmental degradation (Rao and Akram-Lodhi, 2021; Harcourt and Bauhardt, 2018).

Despite the existence of some variants of feminist theories (liberal feminism, classic Marxist feminism, radical feminism, and socialist feminism), there however exist a strong link between various theories and the environment. Besides, the emergence of ecofeminism creates awareness and emphasises the need to empower women on environmental concerns. Consequently, environmental degradation is associated with women's oppression, and hence the need for every feminist theory to integrate an ecological component (Warren, 1987; Gaard, 1993).

2.2. Empirical literature

While most contemporary studies exploring the role of women empowerment on sustainable development have been devoted to the economic (Anik and Rahman, 2021; Kabeer, 2020) and social (Besnier, 2023; Hornset and de Soysa, 2022) dimensions of sustainable development, the empirical literature on environmental sustainability and women action remains scanty, especially in the context of African economies. Although a majority of the few extant studies argue that women's involvement in the socioeconomic life of a society is crucial to sustainable development, there is still an open debate on the question whether women empowerment promotes or impedes environmental sustainability (Achuo et al., 2025; Sharma, 2022).

From a global perspective, Jie et al. (2023) demonstrated that women's empowerment enhances environmental sustainability, thus supporting the findings of Ergas and York (2012) and Ghasemi et al. (2021), who asserts that women's economic participation propels environmental conservation. Besides, Niaghi (2019) argues that if women's managerial and socioeconomic capabilities are not enhanced, the goal of environmental sustainability may remain a farce. Similarly, Rao (2012) contends that women play a major role in environmental regeneration and conservation. Equally, Achuo et al. (2023) recently revealed that women's economic participation mitigates environmental degradation in Africa. Indeed, although ecofeminist literature largely supports the idea that environmental sustainability is positively

connected to women's political and socioeconomic empowerment, Karamidehkordi (2012) argued that because women rely heavily on natural resources for their livelihoods, they are more susceptible to environmental degradation, thus suggesting the need for decision-makers to prioritize the socioeconomic empowerment of women so as to abate pollution emissions.

Besides the nexus between environmental quality and the socioeconomic dimension of women empowerment, divergent results have equally been revealed by studies focusing on the environmental impacts of women's political empowerment. For instance, Ergas and York (2012) contend that politically powerful women are capable of mitigating CO₂ emissions, thereby promoting environmental sustainability. Similarly, Asongu et al. (2021b) claim that the political empowerment of women can mitigate vulnerability to climate change. The authors equally contend that women's political empowerment essentially influences climate change through education, public spending on education, and governance. In this regard, these findings however diverge from the views of Achudume (2009) who concluded that routine household chores performed by less educated women are associated with environmental degradation. Similarly, Achuo et al. (2025) recently argued that environmental degradation in Africa is associated with women's political empowerment.

Contingent on the reviewed theoretical and empirical foundations, it is evident that women's socioeconomic and political empowerment not only contributes to mitigating gender exclusion, but provides a pathway to ensuring environmental sustainability. Besides, integrating ecofeminist acumens with growth-environmental hypotheses like the EKC, pollution halo and pollution haven insights offers an inclusive framework for sustainability challenges within the context of Africa. Consequently, this study hypothesizes that: "there exists a positive nexus between women's socioeconomic empowerment and environmental sustainability".

Apparently, besides the paucity of literature as regards the underlying relationship between women empowerment and environmentalism, very few of these studies have explored the indirect channels through which women empowerment may influence environmental sustainability. This study therefore fills an important research gap in ecofeminist literature within the context of African economies. Specifically, unlike most extant studies that focus on classical economic and political measures of women empowerment, the current study not only adopts a more comprehensive measure of women socioeconomic empowerment, but also employs disaggregated measures of women empowerment and environmental sustainability in checking for robustness of the empirical results. In addition to critically examining the environmental impacts of women's socioeconomic empowerment, the study explores possible channels through which the socioeconomic empowerment of women can impact the environment.

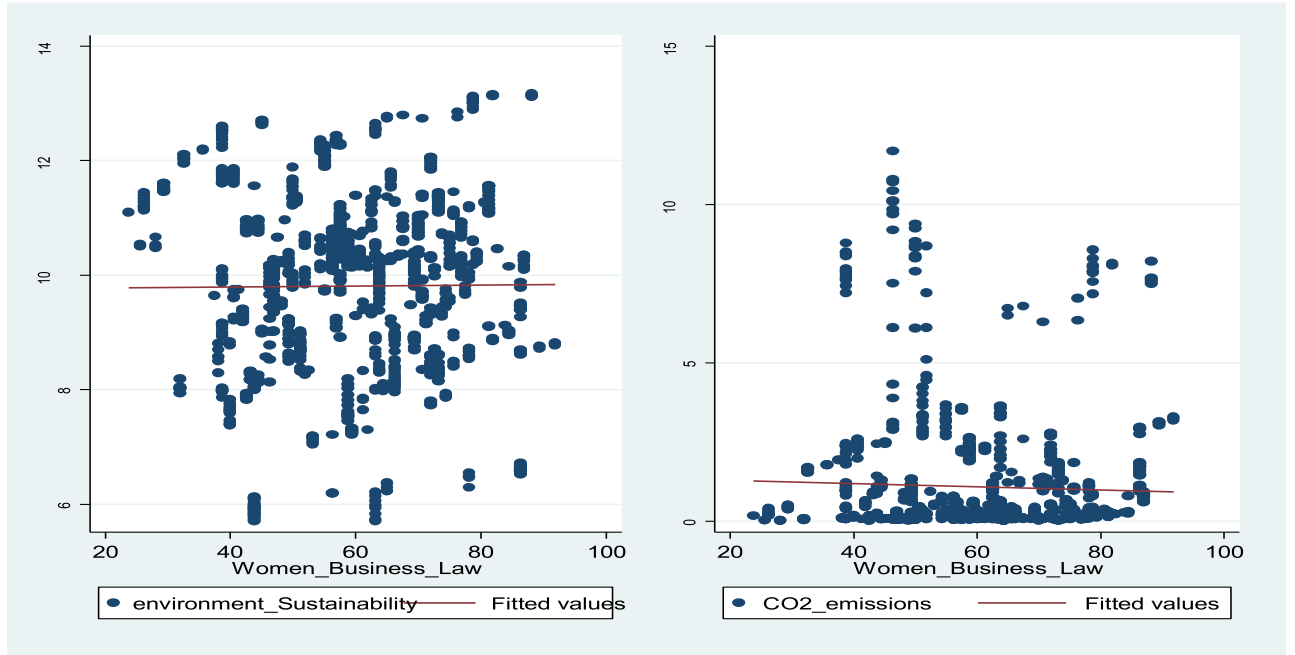
3. Methodological strategy

3.1. Data sources

The study obtained data for 50 African countries (1996-2019) from the 2021 World Development Indicators and the World Governance Indicators of the World Bank. The choice of the retained variables of interest was consistent with the theoretical foundations and recent empirical studies relating to the link between women empowerment and pollution emissions. Although the time scope and choice of sampled countries was partly due to data availability, the time frame and country coverage provides a balanced blend of data consistency, analytical robustness, policy relevance, and representative diversity. Specifically, panel econometric approaches like the system GMM adopted within the context of this study require large samples across both space and time in order to address endogeneity concerns and generate reliable results. Therefore, including 50 African countries not only enhance statistical power and robustness of the results, but ensure policy relevance as it produces findings that are relevant to both national governments and regional bodies that formulate continent-wide gender and sustainability policies. Besides, including 50 African countries provides a comprehensive representation and broad coverage of the diverse economic, ecological, and cultural complexities of Africa. Appendix 1 offers a thorough explanation and definition of these variables. Likewise, Appendix 2 and Appendix 3 provide an overview of the variables' descriptive statistics and correlation analysis, respectively.

However, regarding the correlation between pollution emissions and women empowerment, Figure 1 highlights a negative relationship, suggesting that environmental sustainability is associated with the socioeconomic empowerment of women. Although the apparent relationship may seem negligible in the context of greenhouse gas emissions, the negative relationship becomes significantly more relevant when environmental pollution is measured in terms of CO₂ emissions. Given that socioeconomically empowered women are more likely to lend their voices to the global effort to reduce greenhouse gas emissions and improve environmental quality, there appears to be a negative relationship between women's empowerment and environmental sustainability. This suggests that having a large number of highly empowered women is beneficial to an economy.

Figure 1: Correlation between women empowerment and pollution emissions



Source: Authors' computations

3.2. Model and estimation technique

Contingent on the ecofeminist theoretical foundations and relevant existing empirical research, the relationship between the socioeconomic empowerment of women and environmental quality is explored with the help of the following ordinary least squares (OLS) baseline econometric model in Equation (1):

$$ES_{it} = \lambda_0 + \lambda_1 WSE_{it} + \lambda_2 X_{it} + \varepsilon_{it} \quad (1)$$

Where ES stands for environmental sustainability, WSE stands for women's socioeconomic empowerment, X is a vector of control variables, ε is the random error term, λ_0 is the intercept, λ_1 and λ_2 are slope coefficients. Subscripts i and t represent the individual and time dimensions of the panel.

The dependent variable, ES is captured in this study by total greenhouse gas (GHG) emissions and CO2 emissions. The use of these proxies is consistent with recent environmental studies (Achuo and Ojong, 2025; Achuo et al., 2022; Allaeva et al., 2025; Nigmatullaeva et al., 2025). On the other hand, the independent variable of interest WSE, is proxied by the "Women Business and Law Index" (WBLI). The WBLI, developed by the World Bank (2020), looks at rules and policies that impact women's opportunities as workers and business owners. The WBLI is based on eight indicators that are scored on a range of 1 to 100. The greatest possible score is represented by 100, and the scores are determined by averaging each indicator. It is more appealing to use this index as a proxy for women empowerment than traditional socioeconomic indicators due to the wide scope it covers. As a result, it is expected that the

WBLI is likely to improve environmental quality; that is, better scores will result in less pollution emissions.

A number of classical measures of women empowerment (notably female employment, female self-employment, female wage and salaried workers, women in parliament), and other control variables including resource rents, GDP, FDI inflows, trade, population, and governance, are used in our specified model to account for omitted variables bias. These variables were included in accordance with contemporary research and ecofeminist theoretical foundations (Achuo et al., 2022; Asongu et al., 2021a). Details regarding the definition and a priori expected environmental impacts of these variables are highlighted in Appendix 1.

Besides, considering the established empirical linkages between GDP, FDI and environmental quality (Dinga et al., 2022; Achuo and Ojong, 2025), and the proven association between GDP, women empowerment and FDI inflows (Bui et al., 2018; Ashraf et al., 2025), GDP and FDI can be perceived as key channels through which the environmental impacts of women empowerment are moderated. Consequently, to account for these transmission channels, multiplicative interaction terms of GDP and FDI are added to Equation (1), leading to the formulation of Equation (2) as follows:

$$ES_{it} = \lambda_0 + \lambda_1 WSE_{it} + \lambda_2 GDP_{it} + \lambda_3 FDI_{it} + \lambda_j X_{it} + \beta_1 (GDP_{it} \times WSE_{it}) + \beta_2 (FDI_{it} \times WSE_{it}) + \varepsilon_{it} \quad (2)$$

Where $\lambda_1, \lambda_2, \dots, \lambda_j$ reflect parameter coefficients corresponding to the variables highlighting the direct impacts of the determinants of environmental quality. On the other hand, β_1 and β_2 denote parameter coefficients of variables depicting the conditional impact of the policy moderating variables through which WSE impact environmental quality. A proper appreciation of the interactive regressions requires that Equation (2) is differentiated with respect to WSE as follows in Equation (3):

$$\frac{\partial ES_{it}}{\partial WSE_{it}} = \lambda_1 + \beta_1 GDP_{it} + \beta_2 FDI_{it} \quad (3)$$

Where ∂ is the partial derivative operator. Depending on the sign and magnitude of λ_1 and β_i , the interaction effect may produce net effects. Specifically, a net effect is produced when λ_1 and β_i are both significant but have opposing signs. However, when λ_1 and β_i have the same sign or when at least one of them is non-significant, there is no net effect. Consequently, the net effects for the moderating variables are computed as follows in Equation (4):

$$\text{Net effect of GDP} = \lambda_1 + (\gamma \times \beta_i) \quad (4)$$

Where γ is the mean value of the policy moderating variable, λ_1 and β_i respectively represent the size of the direct and indirect impacts.

The establishment of a net effect for a moderating variable necessitates the computation of the corresponding threshold value. To compute the threshold value, we equate Equation (3) to zero and resolve it for each moderating variable. Consequently, resolving Equation (3) yields the threshold values for FDI and GDP as depicted in Equation (5).

$$\text{Threshold} = \frac{\lambda_1}{\beta_i} \quad (5)$$

Determining this threshold is crucial because it informs decision-makers on the appropriate policy actions to adopt when the moderating variables reach the computed critical values. Besides, contingent on the underlying condition that λ_1 and β_i have opposite signs, the established threshold value must be positive.

However, the underlying relationship between women empowerment and pollution emissions is unraveled using the system Generalised Method of Moments (GMM) estimator proposed by Roodman (2009), which assumes stationarity of the data generating process. The use of the system GMM approach is in conformity with contemporary research (Jacob and Osang, 2020) due to its ability to control for cross-sectional dependence and instrument proliferation. Moreover, the system GMM approach is appropriate when the number of cross sections exceed the number of time periods. This further justifies the use of this approach in the current study which is based on 50 African economies ($N=50$) covering the period 1996-2019 ($T=24$). Moreover, the GMM estimator is consistent when there is a high degree of correlation between the current and lagged values of the dependent variable. Thus, the high correlation coefficient of 0.999 (see Appendix 2) between environmental sustainability and its lagged value makes the adoption of this technique appropriate. Besides, consistent with extant research on GMM estimations (Nchofoung et al., 2021b) arguing that endogeneity is suspected in all explanatory variables due to issues with identification, simultaneity, and exclusion restriction, this study utilizes period dummies in order to ensure the strict exogeneity of our instruments. Besides, the robustness of the system GMM estimator is demonstrated in its ability to simultaneously integrate the level and difference equations. Accordingly, the specified system GMM model in the context of this study is as follows in Equation (6) and Equation (7):

$$ES_{it} = \lambda_0 + \lambda_1 ES_{i(t-1)} + \lambda_2 WSE_{it} + \sum_{h=1}^k \lambda_h X_{h,i(t-1)} + \psi_t + \Omega_i + \varepsilon_{it} \quad (6)$$

$$ES_{it} - ES_{i(t-1)} = \lambda_1 (ES_{i(t-1)} - ES_{i(t-2)}) + \lambda_2 (WSE_{it} - WSE_{i(t-1)}) + \sum_{h=1}^k \lambda_h (X_{h,i(t-1)} - X_{h,i(t-2)}) (\psi_t - \psi_{t-1}) + (\varepsilon_{it} - \varepsilon_{i(t-1)}) \quad (7)$$

Where Equations (6) and (7) denote the respective level and difference equations; ψ_t and Ω_i respectively denotes the time-invariant constant and country fixed effects.

3.3. Data Limitations

Despite the use of internationally recognised and harmonized datasets for the selected countries in the context of this study, it is important to acknowledge potential limitations associated with the quality and aggregation of indicators. Firstly, the employed data especially within the context of African countries may be subject to measurement errors and inconsistencies. This is because the institutional and technical challenges faced by African countries in the data collection process (Shaffer et al., 2018; Dlamini and Synman, 2017) are likely to affect the accuracy of reported data values relating to women empowerment and environmental indicators. Besides, the employed data may suffer from aggregation bias because the use of national level indicators is likely to disguise sub-national disparities. National-level measures of environmental degradation and women empowerment indicators may mask substantial localized realities and sub-national disparities. For instance, there are often substantial disparities between women empowerment in rural areas compared to urban areas. Notwithstanding, the use of the internationally harmonized datasets within the context of this study helps in enhancing reliability compared to reliance on national-level sources only.

4. Empirical findings

4.1. Direct effects

In presenting the unconditional effects of women empowerment on environmental quality, we begin with baseline results and then proceed to the verification of the robustness of the baseline findings by using a variety of proxies for women's socioeconomic empowerment (WSE).

The baseline findings are presented in Table 1. The baseline OLS estimates (Column 2) indicate that WSE leads to environmental degradation, as depicted by the significant positive coefficient of 0.0132 at the 1% level of significance. In addition, the OLS results show that, although GDP per capita and natural resource rents contribute to environmental deterioration, other control variables such as population density, trade openness, and the rule of law improve environmental quality.

Nevertheless, given the established high correlation between the dependent variable and its lagged values, as well as other independent variables, it is necessary for lagged term to be included in the empirical model (Nchofoung et al., 2021 a). Consequently, there is need for the adoption of a more reliable estimation method since the OLS estimators become biased in the presence of the lag dependent variable.

As a result, we focus on the system GMM estimates (Model 2, Column 3) based on the inherent advantages the GMM estimator. Basically, the system GMM results show that environmental quality is greatly impacted by past values. The negative coefficient (-0.000159) of the WSE suggests that women empowerment improves environmental sustainability in Africa. The system GMM results further show that both per capita GDP and foreign direct investment (FDI) are environment-enhancing. This environment-enhancing effect women socioeconomic empowerment is in harmony with the conclusions of Rao (2012) who contends that women play a major role in environmental regeneration and conservation.

Table 1: Effect of women empowerment on environmental quality

Variables	Model 1	Model 2
	OLS	System GMM
Dependent variable: GHG emissions		
GHG emissions (-1)		0.999*** (0.00124)
Women socioeconomic empowerment	0.0132*** (0.00330)	-0.000159* (8.56e-05)
Natural resource rents	0.0132*** (0.00439)	0.000428*** (0.000101)
Gross Domestic Product (log)	0.480***	-0.00873***

	(0.0573)	(0.00148)
Governance	-0.293***	0.00939***
	(0.0873)	(0.00268)
Foreign Direct Investment	0.00533	-0.000105**
	(0.00765)	(4.32e-05)
Population	-0.00363***	2.03e-05**
	(0.000392)	(8.55e-06)
Trade	-0.0170***	3.45e-05
	(0.00135)	(2.66e-05)
Constant	6.409***	0.117***
	(0.545)	(0.0186)
Observations	849	711
R-squared	0.266	
Fisher	43.59***	142014***
Instruments		33
AR(1)_ Proba.		0.117
AR(2)_ Proba.		0.548
Hansen_Proba.		0.299

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Besides, the consistency of the established negative association between WSE and pollution emissions is verified with the employment of other important measures of women's socioeconomic empowerment including female employment, female wage and salaried workers and female labour force participation. The robustness of the baseline results is equally verified by employing an alternative classical measure of environmental quality, notably CO2 emissions.

The ensuing findings in Table 2 reveal that the employment of other socio-politico-economic indicators of women empowerment remains consistent with our baseline results, indicating that women empowerment is environment enhancing. Specifically, Models 1, 2 and 5 (respectively in Columns 2, 3 and 6) reveal that respective economic indicators notably female employment, female wage and salaried workers and female labour force participation are all environment enhancing. It should be noted that the nature of female employment plays a great role in environmental sustainability. This is because, of all the employment indicators used, only female self-employment is environment degrading as evidenced by its positive coefficient (Model 3, Column 4). This positive correlation between female self-employment and environmental degradation suggests that the nature of employment matters, especially within the African context where most self-employed women are concerned with the informal sector with little or no government regulation for their activities vis-à-vis environmental protection.

Due to the fact that most ecofeminist studies have focused on the political empowerment of women, the present study also included a political indicator of women empowerment (Model

4 of Table 2). Specifically, the findings suggest that environmental sustainability is associated with women's political empowerment. These results are in agreement with the conclusions of Asongu et al. (2021b) in a related study in the context of developing economies.

Given that this study primarily employed the GHG emissions as a proxy for environmental quality unlike other contemporary works that employ CO₂ emissions as a proxy for environmental quality (Miamo and Achuo, 2022), there was need to verify the reliability of our baseline results by estimating another model with CO₂ as a dependent variable. Consequently, findings of the CO₂ model (Model 6 in Table 2) remain consistent with our baseline results, thereby confirming the robustness of our baseline findings.

Table 2: Robustness checks using alternative measures of women empowerment and environmental quality

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Dependent Variable					
Variables	GHG emissions				CO2 Emissions	
GHG emissions (-1)	1.001*** (0.00142)	0.999*** (0.00118)	0.999*** (0.00117)	1.001*** (0.00153)	1.000*** (0.00138)	
Female employment	-0.000179 (0.000134)					
Natural resource rents	0.00102*** (0.000269)	0.000724*** (0.000212)	0.000761*** (0.000206)	0.000737* (0.000414)	0.000998*** (0.000251)	0.00211*** (0.000295)
Gross Domestic Product	-0.0163*** (0.00297)	-0.0120*** (0.00256)	-0.0128*** (0.00253)	-0.0113*** (0.00377)	-0.0169*** (0.00270)	0.00891** (0.00373)
Governance	0.0149*** (0.00493)	0.0146*** (0.00432)	0.0147*** (0.00425)	0.0114* (0.00619)	0.0145*** (0.00455)	0.0304*** (0.00712)
FDI	-0.000400** (0.000169)	-0.000278*** (9.28e-05)	-0.000308*** (9.51e-05)	-0.000498 (0.000644)	-0.000413** (0.000162)	0.000725*** (9.34e-05)
Population	3.93e-05*** (1.11e-05)	2.87e-05*** (8.59e-06)	3.16e-05*** (8.62e-06)	4.66e-05*** (1.16e-05)	3.85e-05*** (1.06e-05)	2.53e-05 (2.63e-05)
Trade	0.000124* (7.28e-05)	0.000159*** (4.09e-05)	0.000158*** (4.08e-05)	0.000116 (7.17e-05)	0.000138* (7.07e-05)	-0.000235*** (5.35e-05)
Female wage & salaried workers		-0.000163** (7.86e-05)				
Female self-employed			0.000149* (7.97e-05)			
Women in parliament				-0.000308** (0.000148)		
FLFP					-0.000276** (0.000130)	
CO2 emissions (-1)						0.994*** (0.00115)
WSE						-0.000437** (0.000191)
Constant	0.149*** (0.0286)	0.122*** (0.0240)	0.114*** (0.0240)	0.102*** (0.0305)	0.161*** (0.0275)	-0.0687* (0.0382)

Observations	711	711	711	632	711	711
Instruments	17	25	25	17	17	25
AR(1)_Proba.	0.118	0.118	0.118	0.143	0.118	0.243
AR(2)_Proba.	0.560	0.561	0.561	0.511	0.562	0.360
Hansen_Proba.	0.800	0.261	0.307	0.139	0.833	0.242
Fisher	83683.12***	115736.19***	115786.32***	63297.70***	90342.74***	219425.52***

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, WSE=women socioeconomic empowerment, FDI= Foreign direct Investment, FLFP=Female labour force participation

4.2. Conditional effects

We investigate the main transmission pathways through which women's empowerment affects environmental sustainability in order to account for the conditional effects of women's empowerment on environmental quality. Table 3 presents these findings.

Table 3: The moderating role of GDP and FDI inflows on the women empowerment and environmental quality relationship

Variables	Model 1 Dependent variable: GHG emissions	Model 2
GHG emissions (-1)	0.870*** (0.0228)	0.724*** (0.0449)
Women socioeconomic empowerment (WSE)	0.0137*** (0.00329)	0.00371*** (0.000726)
Natural resource rents	0.000234 (0.00103)	5.48e-05 (0.000269)
Gross Domestic Product (GDP)	0.115* (0.0616)	0.117*** (0.0251)
Governance	0.000814 (0.0201)	-0.0110 (0.0161)
Foreign Direct Investment (FDI)	-0.00260* (0.00137)	0.0241*** (0.00393)
Population	0.000599*** (0.000141)	0.00104*** (0.000252)
Trade	0.000435 (0.000286)	0.000261 (0.000166)
GDP × WSE	-0.00144*** (0.000383)	
FDI × WSE		-0.000386*** (6.18e-05)
Constant	0.162 (0.369)	1.470*** (0.316)
Net effects	0.0021 (GDP)	0.0035 (FDI)
Thresholds	9.514 (GDP)	9.611 (FDI)
Observations	815	815
AR(1)_Proba.	0.110	0.109
AR(2)_Proba.	0.674	0.595
Instruments	19	28
Hansen_Proba.	0.165	0.476
Fisher	2614***	3113***

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 3 identifies two main pathways via which women's empowerment impacts the environment. First, the statistically significant negative coefficient of -0.00144 (Model 1, Column 2) relating to the interaction between GDP and WSE reveals that women's empowerment improves environmental quality. A similar effect is observed following the interaction FDI inflows and WSE (Model 2, Column 3). Thus, based on the methodological strategy highlighted, respective net effects of 0.0021 and 0.0035 are established for GDP and FDI inflows. These

positive net effects are nullified upon attainment of threshold values of 9.514 (per capita GDP, in log form) and 9.611 (FDI as a % GDP) respectively.

To put the above computation into greater perspective, in Model 2 of Table 3, the net effect of WSE on GHG emissions, contingent on FDI is $0.0035 = (-0.000386 \times 0.600) + 0.00371$. In the corresponding computation, 0.600 is the mean value of FDI, 0.00371 is the unconditional effect of WSE while the corresponding interactive effect is -0.000386. The attendant FDI threshold at which the net effect of 0.0035 becomes zero is 9.611 ($0.00371/0.000386$). It follows that above the established threshold of FDI, the overall effect of WSE on GHG changes from positive to negative. As a point of illustration, if the new FDI threshold is 10.000 (i.e., above the critical mass of 9.611), the net effect of WSE on GHG becomes negative or $-0.0001 = (-0.000386 \times 10.000) + 0.00371$. It follows that policy makers should ensure the FDI targets exceed the FDI threshold in order for the positive effect of WSE on GHG emission to be negative. Such understanding of thresholds for greater policy relevance is consistent with contemporary sustainable development literature (Iheonu et al., 2025; Manu and Asongu, 2025).

It is important to clarify that a correlation analysis does not engender policy implications and thus is not indispensable. Moreover, from a technical point of view, in interactive regressions, the concern of multicollinearity that is apparent from a correlation analysis is taken into account by not interpreting the independent variables of interest as in linear additive models (Brambor et al., 2006). It is for this reason that thresholds and net effects are computed in order not to interpret the effect of the socioeconomic empowerment of women exclusively from a linear perspective.

The established thresholds are important in informing policymakers on the critical levels of GDP and FDI inflows at which the socioeconomic empowerment of women promote environmental sustainability. Besides, the interactive regression results indirectly validate the Environmental Kuznets Curve (EKC) hypothesis in the context of Africa, not least, because it is at a certain threshold of GDP per capita (in log form) that the socioeconomic empowerment of women boosts environmental sustainability. Hence, the study does not authenticate the Pollution Haven Hypothesis (Achuo and Ojong, 2025) for FDI values above the established threshold; and by extension, does not validate the Pollution Halo Hypothesis (Bulus and Koc, 2021) for FDI values below the critical FDI thresholds. This perspective of a Pollution Haven Hypothesis (Pollution Halo Hypothesis) below (above) a critical threshold of the FDI variable also applies to the GDP per capita (in log form) moderating variable. Overall, the findings are consistent with the scholarly perspective that, like most economic activities, female socioeconomic empowerment is associated with environmental pollution (Iheonu et al., 2025; Manu and Asongu, 2025). However, there are environmental sustainability benefits associated with higher levels of income and FDI as confirmed by the study.

5. Concluding remarks and policy implications

5.1 Conclusion

The present study empirically probed into the direct and indirect environmental impacts of the socioeconomic empowerment of women Africa. Adopting the system Generalized Method of Moments approach, the findings show that environmental sustainability is associated with the socioeconomic empowerment of women. The results equally show that FDI inflows and per capita GDP have a moderating influence on the environmental impact of women empowerment, with corresponding net effects of 0.0035 and 0.0021.

5.2 Theoretical implications

The findings confirm both the Pollution Halo Hypothesis and the Pollution Haven Hypothesis, depending on the whether the moderating variables are above or below the established critical levels of the moderating variables. It follows that in terms of theoretical underpinnings, scholars who have been understanding the nexus between female socioeconomic empowerment and environmental degradation as a linear phenomenon are getting their dynamics wrong, not least, because when the extant theoretical underpinnings are adapted to more real world scenarios in which the socioeconomic empowerment of women and environmental pollution do not interact in isolation, the theoretical perspective becomes different. Hence, the study has reconciled two theoretical strands of the literature by showing that below the critical levels of GDP per capita and FDI, the Pollution Haven Hypothesis is valid. However, above the established thresholds of the moderating variables, the Pollution Halo Hypothesis withstand empirical scrutiny.

The established findings also improve understanding of the ecofeminism theory with the view that ecofeminism, understood in isolation is unlikely to engender environmental sustainability unless such an idea of empowering women socioeconomically for favourable environmental outcomes is complemented with other macroeconomic policy variables such as GDP per capita and FDI. In other words, the study has improved the theoretical understanding by showing that the effectiveness of ecofeminism is contingent on higher levels of economic development and FDI, such that wealthier countries as well as countries more open to FDI are likely to better experience the positive effects of empowering women socioeconomically on environmental quality.

5.3 Policy and practical implications

The established findings have shown that the positive net effects of women socioeconomic empowerment on GHG become nullified above respective threshold values of 9.514 (per

capita GDP, in log form) and 9.611 (FDI as a % GDP). The established threshold levels are essential for policies as regards the nexus between women empowerment and pollution emissions. Contingent on these findings, there is need for African governments to create conducive business environments in order to attract substantial amounts of FDI inflows, capable of propelling sustainable development. In other words, African governments should strive to ensure that the moderating variables exceed the respective threshold values of 9.514 (per capita GDP, in log form) and 9.611 (FDI as a % GDP) so as to boost environmental quality.

Policies that can attract FDI in order to ensure environmental sustainability include: Strategies aimed at drawing FDI while simultaneously safeguarding environmental integrity, commonly termed "Green FDI," which can be centered on boosting regulatory framework, providing specific incentives, and fostering green infrastructure. Key policy instruments for attracting this type of FDI can encompass: (i) Rigorous environmental regulations for FDI, including environmental impact assessments (EIAs) and compulsory environmental reporting benchmarks, designed to appeal to investors seeking long-term predictability and mitigating the risk of becoming pollution havens. (ii) Fiscal and financial encouragements for environmentally-sound projects, such as tax exemptions, tax credits, accelerated depreciation for green technologies, and reduced tariffs on environmentally friendly equipment. (iii) Renewable energy objectives and protocols, where the establishment of explicit, legally enforceable national targets for renewable energy sources (solar, wind, hydropower) stimulates investment in green energy infrastructure. (iv) Green Special Economic Zones (SEZs), involving the creation of industrial areas equipped with specialized green infrastructure, such as access to renewable energy, sustainable waste management systems, and enhanced public transportation. (v) Enhancement of infrastructure and technology transfer through investments in resilient energy grids, water treatment facilities, and digital technologies that can facilitate sustainable industrial operations.

The provided critical thresholds of the moderating variables are critical levels of the policy variables that should be reached at the macroeconomic level. Hence, these are actionable levels of GDP per capita and FDI that are relevant for the promotion of environmental sustainability. It follows that for the sampled countries, policy makers have been informed of the relevant levels of policy variables that they can act upon by putting in place the necessary measures that can boost GDP per capita and FDI beyond the established thresholds.

To increase GDP per capita and draw FDI, a unified approach is essential, concentrating on fortifying the investment landscape, boosting productivity, and cultivating human capital. Relevant policies can involve promoting political and economic equilibrium, alleviating regulatory bottlenecks, and building infrastructure. Specific initiatives that can be enacted are

as follows: (i) Improving the investment climate and regulatory framework via regulatory adjustments or streamlining business setup, permitting, property acquisition, and employment legislation to cultivate a more conducive business environment. (ii) Maintaining strong political stability, rule of law and corruption-control in order to guarantee stable and predictable legal and political structure to mitigate risks for international investors, foster confidence in the economy and diminish operational impediments. (iii) Boosting productivity and human capital through advancements in education and skill development, incentives for Research and Development (R&D), and support for Small and Medium-sized Enterprises (SMEs). (iv) Reinforcing infrastructure and technology via infrastructure development and digital modernization. (v) Deepening international engagement and connections through trade liberalization and promoting backward linkages, whereby policies encourage foreign investors to procure resources from domestic vendors, thereby facilitating technology dissemination and knowledge diffusion. These strategies can yield the greatest effectiveness when adapted to the unique conditions of each nation, striking a balance between the immediate need for capital inflow and the pursuit of enduring, sustainable economic growth.

5.4 Limitations and future research directions

Despite the limited scope of this study within the confines of African countries, the results may have ramifications in other developing countries across the world with comparable growth dynamics to those in Africa. However, this study leaves room for further research especially in relation to other potential moderating variables through which women's empowerment improve environmental quality. Besides, it is important for future studies to adopt appropriate and more robust empirical approaches for country-specific studies, so as to establish appropriate country specific policies to address challenges relating to the existing relationship pollution emissions and women empowerment.

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Appendices

Appendix 1: Definition of Variables

Variable	Symbol	Definition	Expected Sign
Dependent Variables			
Greenhouse gas emissions (log)	GHG	Total greenhouse gas emissions (kt of CO ₂ equivalent)	NA
Carbon dioxide emissions	CO ₂	CO ₂ emissions (metric tons per capita)	NA
Independent/Control Variables			
Women socioeconomic empowerment	WSE	Women Business and the Law Index Score (scale 1-100)	(-)
Female labour force participation	FLFP	Labor force participation rate, female (% of female population ages 15+) (modeled ILO estimate)	(-)
Female employment	FE	Employment to population ratio, 15+, female (%) (modeled ILO estimate)	(-)
Women in parliament	WP	Proportion of seats held by women in national parliaments (%)	(-)
Natural resource rents	NRR	Total natural resources rents (% of GDP)	(+)
Foreign Direct Investment	FDI	Foreign direct investment, net inflows (% of GDP)	(+/-)
Trade	Trade	Trade (% of GDP)	(+)
Population	Pop	Population density (people per sq. km of land area)	(+/-)
Governance	Gov	Rule of Law: Estimate	(+/-)
Female self-employed	FSE	Self-employed, female (% of female employment) (modeled ILO estimate)	(-)
Female wage & salaried workers	FW-SW	Wage and salaried workers, female (% of female employment) (modeled ILO estimate)	(-)
Gross Domestic Product (log)	GDP	GDP per capita, PPP (constant 2017 international \$)	(+/-)

Notes: NA = Not Applicable; Besides Governance that was sourced from the World Governance Indicators, the rest of the variables were obtained from the World Development Indicators of the World Bank.

Appendix 2: Descriptive Statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
GHG emissions	1150	9.811	1.517	5.704	13.171
WSE	1200	59.533	14.602	23.75	91.875
FLFP	1200	56.964	18.349	11.8	87.68
Female employment	1200	52.136	19.548	8.36	86.02
Women in parliament	1070	16.054	11.214	0	63.75
Natural resource rents	1182	11.709	11.948	.001	67.918
FDI	979	0.600	5.463	-32.233	89.233
Trade	1139	72.342	39.651	16.141	347.997
Population	1233	83.107	113.323	2.02	623.503
Governance	1200	-0.680	.626	-2.13	1.077
CO2 emissions	1150	1.094	1.892	.016	11.676
Female self-employed	1200	73.936	24.501	11.82	99.38
Female wage & salaried workers	1200	26.065	24.501	.62	88.18
GDP (log)	1176	8.087	.944	6.227	10.627

Notes: WSE=Women socioeconomic empowerment, FLFP=Female labour force participation, FDI=Foreign Direct Investment, GDP=Gross Domestic Product

Appendix 3: Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) GHG emissions	1.000														
(2) GHG emissions (-1)	0.999	1.000													
(3) WSE	-	-	1.000												
	0.099	0.099													
(4) FLFP	-	-	0.318	1.000											
	0.160	0.160													
(5) Female employment	-	-	0.304	0.979	1.000										
	0.138	0.138													
(6) Women in parliament	0.048	0.048	0.372	0.198	0.175	1.000									
(7) Natural resource rents	0.147	0.147	-	0.068	0.058	-	1.000								
			0.253			0.029									
(8) FDI	-	-	0.039	0.061	0.073	-	0.092	1.000							
	0.059	0.058				0.008									
(9) Trade	-	-	0.039	0.013	-	-	0.221	0.211	1.000						
	0.303	0.302			0.053	0.010									
(10) Population	-	-	0.319	0.046	0.080	0.166	-	-	0.039	1.000					

	0.314	0.313					0.241	0.033								
(11) Governance	-	-	0.321	-	-	0.105	-	-	0.105	0.279	1.000					
	0.186	0.185		0.259	0.308		0.488	0.078								
(12) CO2 emissions	0.296	0.294	0.004	-	-	0.054	0.279	-	0.088	-	0.226	1.000				
				0.450	0.520			0.015		0.026						
(13) Female self-employed	-	-	-	0.609	0.684	-	0.099	0.040	-	-	-	-	1.000			
	0.027	0.026	0.014			0.048			0.128	0.179	0.536	0.715				
(14) Female wage & salaried workers	0.027	0.026	0.014	-	-	0.048	-	-	0.128	0.179	0.536	0.715	-	1.000		
				0.609	0.684		0.099	0.040						1.000		
(15) GDP	0.043	0.040	-	-	-	-	0.103	-	0.432	0.077	0.272	0.413	-	0.542	1.000	
			0.169	0.499	0.555	0.147		0.069						0.542		

Notes: WSE=Women socioeconomic empowerment, FLFP=Female labour force participation, FDI=Foreign Direct Investment, GDP=Gross Domestic Product