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MONEY TALKS, GREEN WALKS: DOES FINANCIAL INCLUSION PROMOTE GREEN SUSTAINABILITY IN AFRICA?

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Money Talks, Green Walks: Does Financial Inclusion Promote Green Sustainability in Africa?

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Abstract:
This study explores the dynamic relationship between financial inclusion and green sustainability across 38 African countries. We constructed an environmental pollution index and a financial inclusion index covering the period 2000-2021 to account for the several dimensions within both indicators and employed them in the System GMM approach. We also tested for intra-regional heterogeneity in Africa. Our empirical results show that financial inclusion, while economically beneficial, poses a significant risk of environmental degradation and has a distinctive inverted U-shaped relationship. A direct link between increases in financial inclusion and pollution alters at a turning point, beyond which further increments in financial inclusion enhance green sustainability. The same pattern is observed for aggregate output. The results hold even when we control for a score of macro-level determinants. Our findings indicate the existence of an intra-regional heterogeneity in that Southern and Western African states exhibit a more significant negative impact on environmental pollution than Eastern Africa. These results remain robust for alternative proxies of green sustainability. We offer valuable insights for policymakers to promote sustainability through inclusive financial practices and policies in Sub-Saharan Africa.

JEL: C23, E44, F64, K32, O55, Q43
Keywords: Environmental Pollution Index, Financial Inclusion Index, Green Sustainability, Sub-Saharan Africa (SSA), System Generalized Methods of Moments (GMM)

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1. Introduction, motivation, and related literature

In recent years, climate change, global warming and other threats to the environment have forced the world, including Africa, to look deeper into sustainability (Udeagha & Muchapondwa, 2022). The African continent, endowed with rich natural resources and diverse ecosystems, faces this dual challenge of fostering economic growth while safeguarding its environmental heritage (Opoku, Acheampong et al., 2022). This challenge includes high levels of carbon emissions, enormous environmental pollution, and an increasing dependence on energy sources. The exploitation of its natural resources (Hsu et al., 2023) and the expansion of economic activities (Ozturk & Ullah, 2022) raises significant environmental challenges. As such, the intersection of economic development and environmental degradation presents a critical area of study in financial inclusion. Grounded in the Resource Mobilisation Theory (McCarthy & Zald, 1977), financial inclusion is pivotal in mobilising funds from a broader population and channelling those funds into productive investments. Hence, since fund accessibility influences income and consumption patterns of individuals or organisations (Ait Lahcen & Gomis-Porqueras, 2021), we ask whether it contributes to sustainable development or worsening environmental challenges. In this paper, we seek to investigate the impact of financial inclusion on green sustainability in Africa, where green sustainability reflects the extent of environmental pollution. By examining this relationship, we aim to provide insights into how financial inclusion can be leveraged to promote sustainable development across the continent.

The term “green sustainability” denotes a concept that primarily emphasises environmental consciousness, practices, and adopting eco-friendly products and services to minimise negative impacts on ecosystems and safeguard the environment for future generations. It is often synonymous with the idea of environmental sustainability (Udeagha & Muchapondwa, 2023). Environmental sustainability encompasses a range of practices, including sustainable transportation, investing in waste-to-energy projects, green building designs, reducing greenhouse gas emissions, conserving biodiversity, promoting renewable energy, and adopting sustainable production and consumption patterns. However, the extent to which financial inclusion can influence this pursuit remains a subject of empirical inquiry. Financial inclusion, in essence, provides affordable and accessible financial products and services to a broader cross-section of society, including individuals traditionally excluded from the formal financial system. The increase in financial accessibility and usage promotes reduced transaction costs, the development of innovative financial products, and the increased coverage of financial services (Beck, 2020). Drawing from the Resource Mobilisation Theory, an increase in financial accessibility is characterised by urbanisation, industrialisation, and economic affluence.

The theory suggests that by expanding access to financial services, a broader base of individuals can participate in economic activities, thereby contributing to the mobilisation of financial resources. Hence, the influence of financial inclusion on environmental pollution can be understood through its impact on funding channels. It empowers (1) companies with access to credit to import heavy machinery for new projects (Ozturk & Ullah, 2022), (2) individuals to finance luxury and energy-intensive or energy-saving equipment and appliances (Ozturk & Acaravci, 2013), and (3) an overall increase in the consumption and production of goods and services (Hafeez et al., 2019). Each of these activities, in its way, produces an impact on the environment. As a result, there is a potential for a diversified and expanded pool of funds that can be directed toward environmentally sustainable initiatives and investments.

According to Le et al. (2020), the impact of financial inclusion on the environment could either take a positive or negative trajectory. The positive facet is evident in how financial inclusion provides access to funds for investments in green technologies, fostering sustainable agricultural practices, clean-energy innovations, and energy-efficient infrastructure like solar panels and wind turbines (Usman et al., 2021). These endeavours reduce reliance on fossil fuels, mitigate greenhouse gas emissions, and strengthen overall environmental sustainability (Ji, Chen, et al., 2021; Ji, Umar, et al., 2021). On the other hand, Le et al. (2020), Frankel and Romer (1999), and Jensen (1996) argue that while access to financial services stimulates manufacturing, industrialisation, and economic activities, its consequences encompass increased carbon dioxide (CO2) emissions, heightened consumption of energy-intensive consumer goods, and augmented demand for polluting energy sources. Considering these arguments, the imperative of balancing financial inclusion with sustainability remains a critical concern, particularly in the African context.

Previous research has explored how financial inclusion or financial development affects carbon emissions in countries like China, Asia, BRICS, and Organisation for Economic Co-operation and Development (OECD) countries (Wang et al., 2022; Liu et al., 2022; Qin et al., 2021; Zaidi et al., 2021; Le et al., 2020). Wang et al. (2022) indicated in their study in China that the development of financial inclusion has a non-linear effect on environmental quality and sustainability, implying that only after reaching a certain degree of development can financial inclusion improve sustainability outcomes as such financial inclusion observes the Environmental Kuznets Curve (EKC) hypothesis in China. However, in the broader Asian region, Hussain et al. (2021) and Le et al. (2020) suggest a potential negative impact on sustainability. Ahmad et al. (2022) revealed that financial inclusion contributes to environmental pollution in the BRICS countries. Dou and Li (2022) extend this understanding by establishing a positive impact of financial inclusion on emissions. However, in the context of energy, where green sustainability is accounted for as an element of energy efficiency. Dai et al. (2022) show that financial inclusion positively impacts renewable energy efficiency for Regional Comprehensive Economic Partnership (RCEP) economies. Notably, digital financial inclusion also supports green sustainability and development by driving technological innovation and the advancement of industrial structures (Wang et al., 2022). According to Lessmann and Kalkuhl (2023), costly financial intermediation creates high-interest rate spreads, which reduces carbon emissions due to lower overall economic growth and increased abatement costs.

The growing research in these areas suggests that financial inclusion can positively and negatively affect the environment, depending on the specific context and factors such as technological innovation and green openness. However, there is a significant gap in understanding this relationship within the specific context of Africa. To the best of our knowledge, no study has delved into the role of financial inclusion in environmental pollution within the unique context of Africa, specifically Sub-Saharan Africa (SSA). Moreover, when it comes to environmental sustainability, few studies have considered its multidimensionality, such as carbon footprint, ecological footprint, and air quality, and how these factors collectively contribute to overall sustainability. The multidimensional perspective is crucial for a comprehensive understanding of sustainability. To assess the impact of financial inclusion, we test the following null hypothesis: *Financial inclusion does not influence environmental pollution levels in SSA.*

The issue under research is quite relevant, considering that SSA is increasingly home to some of the world's fastest-growing economies and large organisations (Melo & Solleder, 2022). The region is poised to suffer the most from further global warming due to its position as one of the hottest regions on earth (Asafu-Adjaye, 2014). Figure 1 underlines the considerable variations in emission intensity levels among African nations and the startling fact that carbon emissions from energy sources recorded an average annual growth rate of 1.4% from 2012 to 2022 (Energy

Institute, 2023)[1]. Furthermore, financial inclusion is expanding with regional integration and globalisation (Demirgüç-Kunt et al., 2022). As of 2021, almost 55% of Sub-Saharan adults had access to financial accounts (Demirgüç-Kunt et al., 2022)[2]. This assertion is further illustrated in Figure 2, highlighting the varying levels of financial inclusion across different regions. Given these economic and financial shifts, it becomes imperative to explore the role of financial inclusion in shaping the environment within the SSA landscape. Hence, we also empirically test the following null hypothesis: *There is no intra-regional heterogeneous influence of financial inclusion on environmental pollution levels in SSA.*

Concerning the economic impact of financial inclusion, existing studies suggest the presence of a non-linear inverted U-shaped relationship. The non-linear pattern aligns with the Environmental Kuznets Curve (EKC) hypothesis introduced by Grossman & Krueger (1995) in the context of economic development. According to the EKC hypothesis, environmental degradation occurs during the early development phase. Beyond a certain level of development, the economic benefit of growth becomes more affluent for environmental preservation. Though the EKC hypothesis is in the context of economic growth, it allows for relevant macroeconomic variables that are theorised to influence environmental sustainability (Qin et al., 2021), including financial inclusion (Qin et al., 2021; Renzhi & Baek, 2020; X. Wang et al., 2022). In the spirit of the non-linear relationship, we explore the EKC traditional theory within the context of financial inclusion. Our primary goal is not to test the traditional EKC hypothesis but to determine whether an adjusted model could be linked to the concept of financial inclusion. Hence, we empirically test the following null hypothesis: *There is no non-linear U-shaped relationship between financial inclusion and environmental pollution levels in SSA.*

We assessed how financial inclusion impacts green sustainability using a dynamic panel model based on the Resource Mobilisation Theory (McCarthy & Zald, 1977). We applied the System Generalized Methods of Moments (GMM) to test our hypothesis and account for potential endogeneity. We employed annual macro-level data from 2000 to 2021 using 38 SSA countries[3]. We used the Principal Component Analysis (PCA) to construct an environmental pollution index

[1] Third highest region in the world after Middle East (1.9%) and Asia Pacific (1.7%).

[2] From 2017 to 2021, the average rate of account ownership in developing economies increased by 8 percentage points, from 63 percent of adults to 71 percent of adults. In Sub-Saharan Africa, this expansion largely stems from the adoption of mobile money (Demirgüç-Kunt et al., 2022).

[3] We do not perform estimation at micro-level as insights from such study would serve as further studies in a different paper with different research questions. This decision also stems from limitations in micro-level data accessibility, necessitating a different approach to data collection and analysis.

to measure Green Sustainability. Following the example of Opoku et al. (2022), the index captures four (4) environmental pollutants, including Particulate Matter (PM) 2.5, CO_2 emission, methane emission, and nitrous oxide emission. We also employed renewable energy consumption as a measure of green sustainability. Our justification is based on empirical evidence highlighting the positive effect of renewable energy on air quality through controlling carbon emissions and lowering the direct interaction of households with toxic gases (Hanif, 2018). Renewable energy such as hydropower presents an appealing method for energy generation in addressing climate change, as they are promoted as a substitute for traditional fossil fuels (Castro-Diaz et al., 2023). We also employed a multidimensionality of financial inclusion to create a financial inclusion index. Our findings suggest that financial inclusion poses an unfavourable influence on the environment by facilitating the demand for more disposable goods and encouraging rapid expansion, leading to more waste generation and environmental pollution. On the other side, financial inclusion promotes the use of renewable energy.

Our research contributes significantly to the literature as it provides a novelty in the case of SSA. First, we assess how financial inclusion can be leveraged to create a sustainable environment and further combat climate change. As such, we include a composite measure of green sustainability, which has not been employed as a factor in previous research, and test a non-linear relationship between financial inclusion and environmental pollution levels. Second, we provide a more focused analysis among the regions in SSA by conducting an intra-regional heterogeneity test to assess how this impact of financial inclusion on the environment differs among the various regions. Third, we provide more robust outcomes by controlling for innovative variables affecting the environment, such as urbanisation, trade openness, energy use, and human development. Fourth, we provide a clear insight into the magnitude of each financial inclusion indicator on the separate covariates of the environmental pollution index, as one indicator may affect the environment differently. The same insight is provided for separate pollutants that primarily impact climate change. Lastly, we provide policy recommendations on how financial inclusion could be applied by adopting innovative products like green loans, green bonds, and green credit score models to promote and strengthen the environment in SSA.

The paper is structured as follows: the next section describes the data and measurement methods, Section 3 provides the methodology and main estimations employed, Section 4 presents and discusses the main empirical results, section 5 presents the results of robustness tests and finally, Section 6 concludes and offers policy directions and suggestions for future research.

2. Data

We used panel data with annual frequencies covering 38 Sub-Saharan African (SSA) countries from 2000-2021 to investigate the role of financial inclusion on green sustainability, along with other country-level information detailed later in this section. The countries included in our study are listed in Appendix Table A1. The chosen period is motivated by the need to capture long-term trends, economic changes such as how financial inclusion has evolved and deepened to include more focus on sub-national data mostly since 2000, and environmental concerns in SSA, including the oil spills in Nigeria and the discovery of oil in Ghana. The data were sourced from the World Development Indicators database, the Global Financial Development Database and the Our World in Data. Appendix Tables A2, A3 and A4 list all the data used in our study.

2.1 Measure of Green Sustainability and Financial Inclusion

We measured green sustainability and financial inclusion by constructing an environmental pollution index (EPI) and a financial inclusion index (FII) to account for the several dimensions of both variables. Specific dimensions are defined with the help of relevant variables in Appendix Tables A3 and A4. We further introduced macro-level dependent variables to serve as controls.

2.1.1 Green sustainability measure

Following the example of Opoku et al. (2022), we measured green sustainability to depict the level of pollution intensity using an environmental pollution index. The index was constructed using four different environmental pollution variables, namely CO2 emissions, Particulate Matter 2.5 (PM), methane emissions, and nitrous oxide emissions. These variables were carefully selected to capture different facets of pollution, such as ecological footprint, carbon footprint, and air quality. We also avoided the issue of double-counting various pollution indicators.

CO2 emissions reflect the release of carbon oxide gas into the atmosphere primarily from activities like burning fossil fuels, solid waste, and trees. CO2 emission is measured in metric tons per capita, and by dividing the total emissions by population, it captures the contribution of the average citizen of each country. CO2 emissions have been associated with increased global warming and climate change concerns, making it a crucial indicator for evaluating environmental sustainability (You et al., 2015). Mitigating CO2 emissions is vital for curbing the adverse impacts of climate change, including extreme weather events and rising sea levels.

PM assesses the local level of air pollution and air quality. We employed PM as a variable to measure the concentration of small airborne particles, including dust, dirt, soot, smoke and liquid droplets. It primarily originates from various sources, including industrial processes, bushfires, pollens, sea spray, dust storms and motor vehicle engines (Isphording & Pestel, 2021). However, our empirical analysis focuses on PM 2.5 to measure particles up to a diameter of 2.5 microns. PM 2.5 is a commonly employed key indicator in literature to measure exposure to air pollution, and it stands as the fifth most significant risk factor contributing to global mortality (Cui et al., 2023). High levels of air pollution are detrimental to human health and the environment and can sometimes cause sleeplessness (Heyes & Zhu, 2019), making it an essential aspect of environmental sustainability.

Further, methane emission captures the emissions from agricultural activities, livestock farming, and waste management. Methane emission has implications for climate change due to the high heat-trapping ability of methane (CH_4) compared to carbon dioxide. As is common in environmental research, the CH_4 variable is measured as an equivalent of the metric tons of CO_2 per capita. Finally, nitrous oxide emission captures emissions from agriculture and wastewater containing organic-based nitrogen materials. It is essential to note that not all types of nitrous emissions are considered. Instead, we focus specifically on one subset—nitrous oxide (N_2O), which is a greenhouse gas with a longer atmospheric lifetime than other greenhouse gases. The primary source of N_2O is the agricultural sector (Krüger & Tarach, 2022). While nitrous oxide is present in substantially smaller concentrations than carbon dioxide, nitrous oxide emission represents a much higher global warming potential (Paolini et al., 2018). Again, the N_2O variable is measured in metric tons of CO_2 equivalent per capita to provide a comparative perspective when assessing the impact of different greenhouse gases.

We also conducted a re-estimation using renewable energy as a single measure of green sustainability for robustness checks. Adopting renewable energy encourages a shift towards a more sustainable lifestyle and practice and the use of affordable and clean energy, as it does not produce additional greenhouse gases (Leroutier, 2022). It promotes energy efficiency, embraces eco-friendly technologies, combats climate change, and conserves natural resources. As such, using renewable energy as a measure helps gauge the reduction in greenhouse gas emissions and other pollutants, directly contributing to environmental sustainability.

As a further robustness check, we separated the pollutants that impact urban air quality (such as PM2.5) from those that primarily impact climate change (CO_2, CH_4, N_2O). In order to use the latter as a single measure, we constructed an index termed the climate footprint index (CFI). The equation for the index is described in Sub-section 2.1.3. We adopt this approach due to the distinct origins of our emissions variables—specifically, CO2, methane, and nitrous oxide emissions. These variables have been weighted based on their Global Warming Potential and differ slightly from PM2.5. Our approach is also to help gain insight into how financial inclusion impacts climate change in SSA. Finally, we performed another test examining the impact of financial inclusion on individual pollution indicators.

2.1.2 Financial inclusion measure

We assess financial inclusion by constructing a comprehensive Financial Inclusion Index (FII) comprising six variables. The index considers the multidimensional nature of financial inclusion, encompassing accessibility, usage, and the quality of financial services and products. Appendix Table A4 summarises the dimension defined with the help of relevant variables. Our rationale for this multifaceted approach is rooted in the understanding that true financial inclusion is not fully realised unless all these dimensions are effectively addressed. For instance, the mere presence of ATMs in proximity to individuals is unsatisfactory if those ATMs are non-functional or inaccessible (Nguyen, 2021).

To measure the accessibility dimension, we employed two key variables: ATMs per 100,000 adults and bank branches per 100,000 adults. These factors account for the physical availability of financial service points provided by financial institutions (Ugwuanyi et al., 2022; Cámara & Tuesta, 2014) and the country's banking infrastructure development.

As previously mentioned, the significance of financial access becomes apparent when it is actively utilised. Utilisation includes various financial activities such as saving, investing, borrowing, and making deposits and withdrawals. Building upon this concept, we utilised bank deposits and bank credits as indicators to quantify the extent of utilisation within the dimension of financial usage.

To measure the quality dimension, we employed two indicators: Life Insurance, captured as the ratio of life insurance premiums to a country's GDP, and Non-Life Insurance, measured as the ratio of non-life insurance premiums to a country's GDP. As denoted by the stated indicators, the quality dimension assesses the financial products or services that address financial needs and reduce financial burdens.

2.1.3 Principal Component Analysis

Further, we constructed the Environmental Pollution and Financial Inclusion Indexes using the Principal Component Analysis (PCA).[4] The PCA method helps to gauge the aggregate effect of the four (4) and six (6) variables related to environmental pollution and dimensions of financial inclusion, respectively (Sharma and Changkakati, 2022). The application of PCA has three advantages: we avoid the problem of weight assignment and arbitrary weights using statistical weights (Cámara & Tuesta, 2014). PCA creates a linear combination of the original variables (principal components), which are orthogonal to each other. After the dimension reduction, statistical weights are applied to the various components based on the contribution of each principal component to the overall index. The weights are determined based on the eigenvalues of the covariance matrix of the standardised variables. We normalised the indices to ensure that all variables contribute equally to the analysis, preventing those with larger scales and variances from dominating the principal components. As such, the higher the eigenvalue, the more significant the variance and importance. We avoid the correlation between different individual indicators and can analyse the aggregate impact of the various factors without omitting any particular one (Iwasaki et al., 2022). To ensure coherent and consistent results, we normalise the various indicators to provide a comparable impact of green sustainability and financial inclusion independently of their original scale.

Hence, we employed the principal component methodology in line with the approach of Sharma and Changkakati (2022) and for every country *i* and period *t*, we developed an environmental pollution index (EPI) and a financial inclusion index (FII). We used the same approach to construct the Climate Footprint Index (CFI). All the indexes ($Index_{it}$) are defined in a similar way as follows:

$$Index_{it} = \sum_{n=1}^{N} \emptyset_n Z_{it} + \varepsilon_{it}, \quad (1)$$

where Z_{it} represents the dimensions associated with both financial services and products and also the dimensions of environmental pollution. The variable N represents the number of factors contributing to the index and the loadings $\emptyset_n$ represents the respective weights for each principal

[4] The PCA approach utilises the summation of weighted contributions from various dimensions associated with variables (in this case, financial services/products and environmental pollution) to create both indices. The use of the principal components ensures that the indices capture the most important variations in the underlying data.

component. The term ε_{it} accounts for errors in the model. The index is constructed so that an increase in financial inclusion increases emissions and, therefore, reduces green sustainability since the function of the index captures environmental pollutants.

The PCA results are presented in Appendix Table A5. The eigenvalues of the first two components explain the majority of variance in the data. The first two components of the environmental pollution and financial inclusion indexes account for 75% and 82% of the total variation, respectively. For the environmental pollution index, variables with higher absolute coefficients (Methane emission, nitrous oxide emission) have a stronger influence on the first principal component, indicating that changes in these variables contribute more to the variability captured by the first component. Variables with lower coefficients (PM25, CO2 emission) have a weaker influence on the first principal component. However, all variables are significant in determining environmental pollution levels.

All original variables have positive coefficients in the first component of the financial inclusion index, indicating that an increase in any of these variables contributes positively to the financial inclusion index.

2.2 Control Variables

Following the standard economic literature, we also accounted for other variables such as energy use (Usman et al., 2021; Sinha et al., 2017), human development[5] (Opoku et al., 2022), natural resource dependency (Li et al., 2023), trade openness (Ali et al., 2016; Ozturk & Acaravci, 2013), economic growth (Ali et al., 2016; Usman et al., 2021), government expenditure (Pirgaip et al., 2023; Halkos & Paizanos, 2016), and urbanisation (Ali et al., 2016) as controls covariates.

We further present the descriptive statistics of variables in Appendix Table A6 and the results of our correlation analysis among variables in Appendix Table A7. We used the pairwise correlation test to determine the magnitude and linear direction between the variables, with -1 being a perfect negative correlation and +1 being a perfect correlation. Our results show no

[5] We do not use the Human Development Index as a proxy for human development as it is highly correlated with urbanisation. We employ one of the single indicators of its composite dimensions to avoid the issue of multicollinearity.

evidence or concerns for multicollinearity in our model[6]. The independent variables have a correlation coefficient of less than 0.7 (Krehbiel, 2004).

3 Methodology

3.1 Model specification

We estimate the effect of financial inclusion on green sustainability through a dynamic panel model rooted in the Resource Mobilisation Theory. The model is based on the assumption that the present value of our selected variable, reflecting environmental pollution, exhibits a strong dependence on its own lagged values (Li et al., 2021). Pollution cumulates and generates damage over time with persistence (Calzolari et al., 2018). Consistent with Li et al. (2021), we adopt a dynamic panel model for individual i at time t of the form:

$$\mathrm{Y_{it}} = \alpha + \sum_{s} \rho_s Y_{i,t-s} + \beta X_{it} + (u_i + \varepsilon_{it}); \;\; (t = 2,3, \dots, T), \tag{2}$$

where s = 1, 2 …, and $Y_{i,t-1}$, $Y_{i,t-2}$ are the values of the lagged dependent variable that affect X_{it}. The coefficient ρ_s captures the autocorrelation in Y, and β measures the effect of X on Y.

The lagged dependence stems from the fact that present environmental pollution levels are shaped by past practices, regulations, or environmental conditions and their likely evolution in the future (Sadorsky, 2010). This recognition emphasises the inherent link between environmental pollution or sustainability and its past values. We further estimate two equations to help test our hypothesis. Following the Resource Mobilisation Theory, and akin to Ozturk and Ullah (2022) and Sadorsky (2010), we break and specify our model assessing the impact of financial inclusion on environmental pollution as:

$$EPI_{it} = \beta_1 EPI_{it-1} + \beta_2 FII_{it} + \sum_{i=1}^{n} \beta_i Z_{it} + \nu_i + \varepsilon_{it}, \tag{3}$$

In the above specification, the EPI represents the environmental pollution index, FII denotes the financial inclusion index, $\sum Z$ represents a vector of control variables, *v* represents the time-invariant country-specific fixed effects, and $\mathcal{E}$ denotes the residual disturbance in the model estimation. The environmental pollution index and financial inclusion index encompass various specific dimensions, as detailed in Section 2.1, while Section 2.2 defines the control variables used.

[6]The Correlations between green sustainability, financial inclusion, energy use, human development, trade openness, natural resource, economic growth, government expenditure and urbanisation ranges between 0.02 and 0.53 and do not lead to problem of multi-collinearity.

We further modified the model to account for a potential non-linear relationship between financial inclusion and pollution. The adapted model incorporating this hypothesis is expressed as:

$$EPI_{it} = \beta_1 EPI_{it-1} + \beta_2 FII_{it} + \beta_3 FII_{it}^2 + \sum_{i=1}^{n} \beta_i Z_{it} + \nu_i + \varepsilon_{it}, \quad (4)$$

Here, FII^2 captures the quadratic term of financial inclusion, accommodating the non-linear relationship postulated by the EKC hypothesis. Further, consistent with the mainstream literature, we modified our specification to include economic growth and its square as core components of the typical EKC model to assess the dynamics of financial inclusion's impact. We specify the model as:

$$EPI_{it} = \beta_1 EPI_{it-1} + \beta_2 FII_{it} + \beta_3 GDP_{it} + \beta_4 GDP_{it}^2 + \sum_{i=1}^{n} \beta_i Z_{it} + \nu_i + \varepsilon_{it}, \quad (5)$$

where GDP and GDP^2 capture the linear and quadratic terms of economic growth in the EKC hypothesis, respectively.

In our robustness test, we re-estimated the model using the climate footprint index (CFI) as a proxy for our dependent variable. We specify the model as follows:

$$CFI_{it} = \beta_1 CFI_{it-1} + \beta_2 FII_{it} + \sum_{i=1}^{n} \beta_i Z_{it} + \nu_i + \varepsilon_{it}, \quad (6)$$

where CFI represents the Carbon Footprint Index, as described in Sub-sections 2.1.1 and 2.1.3.

3.2 Estimation Technique

In line with the above model specifications (3) and (4) and consistent with existing literature, our dependent variable, green sustainability, a proxy by EPI, is considered endogenous. Endogeneity arises from the fact that green sustainability is influenced by its lag values, leading to a dynamic relationship (Law & Azman-Saini, 2012). Endogeneity can also occur in the dynamic model when there is a reverse causality among the independent variables and a reverse causality between the independent variable and financial inclusion (Francois, 2023).

We employ the System Generalized Methods of Moments (GMM) to estimate our results and address the endogeneity issue. The estimation strategy is efficient in handling endogeneity bias, particularly when appropriate instruments are available (Chen et al., 2024). The GMM technique, introduced by Blundell & Bond (1998) and Arellano & Bond (1991), is an instrumental variable method that combines a system of two equations, a model estimated in differences with a model estimated in levels for its estimation. Mathematically, the levels equation for computing the system GMM, according to Li et al. (2021), is computed as:

$$Y_{it} = aY_{it-t} + bX_{it} + yZ_{it} + \mathcal{E}_{it}, \tag{7}$$

where Y_{it} is the dependent variable, X_{it} is the matrix of the exogenous variables, Z_{it} is the matrix of instruments (lagged levels and first differences of endogenous variables and exogenous variables), a and b are the parameters to be estimated, $\mathcal{E}_{it}$ and is the error term.

Subsequently, the first difference equation is specified as:

$$Y_{it} = m\Delta Y_{it-1} + n\Delta X_{it} + q\Delta Z_{it} + \mu_{it}, \tag{8}$$

where $\Delta Y_{it} = Y_{it} - Y_{it-1}$ is the first difference of the dependent variable; $\Delta X_{it} = X_{it} - X_{it-1}$ is the matrix of the first differences of exogenous variables; $\Delta Z_{it} = Z_{it} - Z_{it-1}$ is the matrix of the first differences of instruments; m and n are the parameters to be estimated, and μ_{it} and is the error term.

The System GMM uses moments conditions based on the instrumental variables. These moment conditions are used to construct the weighting matrix of the estimation. For each period t, the moment conditions are given by:

$$E[\Delta Z_{it} \, . \, \mu_{it}] = 0, \tag{9}$$

where, for every t and i in the sample period, the expected value of the idiosyncratic error given the explanatory variables in all periods and the unobserved effect is 0 (Li et al., 2021).

Again, we adopted a panel estimation strategy as it is suitable in two (2) ways: (1) when the cross-sectional (N) units are more than the time series (T) units (Abeka et al., 2022); (2) when there is a tendency for persistence in the lagged differences of the dependent variable using a rule of thumb of 0.80 (Agyei et al., 2020). Thus, the coefficient of the lagged dependent variable should be close to 1.

In our study, T=22 and N=38. From our correlation analysis, the lag value of the dependent variable shows a correlation coefficient of 0.918, which is close to 1 and confirms the presence of lagged persistence. We employed the approach of Roodman (2009) to reduce the possibility of bias from instrument proliferation by restricting the moment conditions to a maximum of two lags of the dependent variable. The number of instruments should be less than or equal to the number of groups to avoid instrument proliferation (David et al., 2023).

We assess the adequacy of our System GMM results and the validity of our instruments by reporting on the Sargan test of over-identifying restrictions (OIR) and Hansen test of over-identifying restrictions (OIR). Similarly, we test for the absence of autocorrelation using the Arellano and Bond serial correlation test. These tests require that the null hypothesis be rejected for the test to be valid. It is usually expected that the null hypothesis for the first order (AR1) will be rejected. Nevertheless, the second order (AR2) is more important because it will detect autocorrelation in levels and therefore, its null hypothesis should not be rejected. As Asongu and De Moor (2017) recommended, we further analyse and report on the difference-in-hansen test (DHT) for the exogeneity of instruments to assess the results of the Hansen OIR test. Fischer's test for the joint validity of estimated coefficients evaluates the validity of the estimated GMM model.

4. Results and Discussion

We present the results of our system GMM model, as detailed in Table 1, which examines the influence of financial inclusion on green sustainability. Our analysis shows that an increase in financial inclusion levels is strongly linked to increased pollution levels in SSA. The findings align with Le et al. (2020), which suggests that an increase in financial inclusion facilitates access to funds for acquiring more big-ticket items such as automobiles, refrigerators, air-conditioners, electricity generators and plants, whose use lies with fossil fuels and results in higher pollution. We further show that financial inclusion can lead to increased consumption of products due to increased purchasing power. While this can stimulate economic growth, it results in higher demand for disposal goods, leading to more waste generation and environmental pollution.

By comparing our results to existing literature, our finding aligns with Usman et al. (2021) in the Eurozone. Similarly, Popescu et al. (2023) confirm that Socially Responsible Investing (SRI) funds may not exhibit lower climate exposure compared to market indexes. They explained that funds labelled as sustainable (SRI) still maintain exposure to highly emitting companies, particularly those with high indirect carbon intensity. However, our results contrast with the findings of Shahbaz et al. (2022) and Renzhi and Baek (2020), who observed that financial inclusion reduces carbon emissions. These differing outcomes may be attributed to variations in the level of development of financial inclusion, industrialisation, technological advancement and innovation, and the preference for advanced gadgets in these countries. Nonetheless, in a region like SSA, where financial inclusion is still in its early stages, a significant increase in financial inclusion creates the urge for rapid infrastructure development for growth, rapid urbanisation in search of economic opportunities, expansion of industries and increased demand for energy. These activities could destroy habitats and disrupt natural ecosystems, causing environmental harm.

4.1 Control for other macroeconomic determinants

We control for other determinants that can collaboratively influence environmental pollution by employing control variables of energy use, human development, natural resource dependency, trade openness, economic growth, government expenditure, and urbanisation. Our findings reveal a significant contribution of energy use (proxied by electricity from oil) in increasing environmental pollution levels. This adverse effect is evident in its negative coefficient and may be attributed to the extensive reliance on fossil fuels like oil for energy generation, transportation, and manufacturing (Le et al., 2020).

Further, we note that higher levels of human development significantly decrease environmental pollution levels. Human development improves awareness and behaviour change through education, contributing to adopting eco-friendly practices and policies. Our findings are consistent with Opoku, Dogah, et al. (2022).

Our analysis suggests that trade openness is linked to decreased environmental pollution levels. The presence of trade liberalisation encourages the alignment of environmental standards and policies with international norms, which fosters collective efforts to reduce pollution across borders. As noted by Le et al. (2020), trade agreements can enhance the capacity of governments to tackle environmental issues by eliminating trade barriers to environmental goods and services. Trade openness often facilitates technology and innovation transfer (Usman et al., 2021) to provide easier access to environmentally friendly technologies and renewable energy sources.

Also, increasing economic growth significantly contributes to high environmental pollution levels. Our result highlights how increased production of goods and services and overall economic expansion can contribute to environmental depletion. Rapid economic growth is associated with elevated energy consumption, intensified industrial activities, and heightened transportation, all of which contribute to environmental stress. In response to such adverse impacts from economic growth, Yuan et al. (2023) suggested adopting and establishing environmental courts, as seen in China. These specialised courts can reduce emissions without hindering economic growth. They achieve this by employing efficient judicial methods to address local environmental pollution problems and establish a sustainable mechanism for environmental governance (Yuan et al., 2023).

We further highlight that government expenditure is linked with a decreasing impact on environmental pollution in SSA economies. An increasing number of government policies and regulations lead to increased government spending and efficient resource allocation, predominantly improving environmental efforts in SSA. According to Magacho et al. (2023), government expenditures are necessary to promote green industries either through direct fiscal stimulus or investment in renewable energy and other green technologies, which effectively reduces pollution. Moreover, many SSA countries are involved in international agreements, including the African Union Agenda 2063, the United Nations Framework Convention on Climate Change (UNFCCC), and the Paris Agreement. These agreements and intergovernmental environmental cooperation foster the advocacy of Clean Development Mechanism (CDM) (Cui et al. 2022) and encourage governments to invest in activities aimed at curbing greenhouse gas emissions, conserving biodiversity, and mitigating climate change.

Also, urbanisation contributes to increasing environmental deterioration in the sampled SSA economies. Urbanisation intensifies environmental effects, impacting air quality, ecosystems, land utilisation, natural cycles, water purity, waste handling, and the climate (Bai et al., 2017).

Finally, we show that the influence of natural resource dependence on environmental pollution is statistically irrelevant. The environmental impact of natural resource dependence may not be solely attributed to the region itself but may be dispersed globally due to the nature of the supply chain (OECD, 2023). The dispersion chain could account for the observed insignificant effect. Countries may export raw materials for processing elsewhere, influencing where pollution occurs in the supply chain. The insignificant effect may also stem from the varied environmental impacts of different natural resources (OECD, 2021). For instance, sustainable forestry may have less impact than oil or minerals. According to OECD (2019, 2021), the environmental impacts of other metals like aluminium, iron, and manganese are projected to remain constant or decrease over time due to the decarbonisation of energy in production and the increased use of secondary materials, which tend to have lower overall environmental impacts compared to primary materials.

4.2 Intra-regional heterogeneity with respect to environmental pollution

We further explored the intra-regional heterogeneous influence of financial inclusion on environmental pollution among the three regions in SSA: Western Africa, Eastern Africa and

Southern Africa.[7] Despite the recent increase in financial inclusion levels across SSA, disparities persist among the various regions. Specifically, Southern Africa exhibits relatively higher levels of financial inclusion than West Africa and East Africa (Sulemana & Dramani, 2022). Additionally, CO2 emission levels, as described in Figure 1, vary among the three regions. Hence, we examine and present the results of our intra-regional heterogeneity test in Table 2, where Eastern Africa is taken as a base and reported effects are measured with respect to it.

Table 2 results indicate a distinct intra-regional heterogeneity in SSA. First, we note that financial inclusion's impact on environmental pollution is 1.52% lower in Southern Africa than in Eastern Africa, which is consistent with the findings of Barut et al. (2023) for South Africa alone. Further, we show that given a 1% increase in financial inclusion in SSA, environmental pollution levels are 1.13% less in Western Africa than in Eastern Africa. Our finding aligns with Musah et al. (2023), showing that financial inclusion reduces environmental pollution in the Western African region. Based on the statistically significant coefficients, we can infer the presence of intra-regional heterogeneity within the Sub-Saharan African regions. Specifically, the impact of financial inclusion in Southern Africa and Western Africa on environmental pollution is smaller than that of Eastern Africa. Hence, the two former regions seem to be in better shape concerning the environmental sustainability.

According to Wang et al. (2022), this heterogeneity could be attributed to varying levels of financial inclusion and regions' reliance on its advantageous geographical location to attract increased investments for environmental sustainability promotion. These results might also be due to these regional communities having varying policies, agreements, or initiatives contributing to environmental sustainability.

4.3 Test of a non-linear relationship

We also examined the existence of the non-linear relationship between financial inclusion and green sustainability in Sub-Saharan Africa. Our analysis in Table 1 revealed a distinctive inverted U-shaped pattern. Specifically, Table 1 shows a positive coefficient of financial inclusion on environmental pollution, indicating its contribution to increasing pollution levels. The effect is not straightforward, though. Since the coefficient of the quadratic term of financial inclusion is

[7] The three regions represent countries that are members of the formal arrangements: the Economic Community of West African States (ECOWAS), the East African Community (EAC), and the Southern African Development Community (SADC). The last one is dubbed as Southern Africa and comprises sixteen members, including (the Republic of) South Africa.

negative and statistically significant, it confirms the presence of a non-linear U-shaped relationship between financial inclusion and environmental pollution in SSA.

These findings suggest that financial inclusion is linked with increasing environmental pollution. Further, the inverted U-shaped effect implies that in the early stages of increased financial inclusion, pollution level increases until it reaches an optimal level. Beyond the turning point, further increments in financial inclusion notably enhance sustainability. The U-shaped phenomenon can be explained by the behaviour of individuals and businesses during different stages of expansion of financial inclusion. Specifically, according to Renzhi and Baek (2020), people primarily focus on improving their living standards and expanding their businesses at the initial stages of increased financial inclusion. Such pursuit often leads to higher consumption and increased environmental degradation. However, at the later stage, individuals gain the capacity to invest in cleaner technologies, engage in more corporate social responsibilities, and explore greener innovations. Consequently, sustainability experiences a substantial improvement during these later stages. The shift aligns with Musah et al. (2023) and Youssef et al. (2020) and outlines the importance of reaching an optimal level of financial inclusion for achieving environmental sustainability in SSA.

Additionally, our result underscores the importance of considering financial inclusion and economic growth dynamics in fostering environmental sustainability. Our findings show that the quadratic term for GDP growth exhibits a negative impact, implying a curvilinear relationship between GDP growth and environmental pollution. Our result supports the typical Environmental Kuznets Curve (EKC) hypothesis (Li, 2023; Hlongwane & Daw, 2022) and serves as a battery test, indicating that our results align with the mainstream literature.

5. Robustness tests

In addition to our baseline estimation, we performed various robustness checks to verify the validity of our results. We explored alternative green sustainability and financial inclusion measures consistent with the approaches outlined in our base model. In Tables 3, 4, and 5, we present the results of our robustness tests, which are consistent and not materially different from our baseline results. Finally, we also re-estimated our baseline model and reported results based on alternative sets of instruments. We present the additional information in Appendix Table A8. The results show similarities with those reported in Tables 1 and 2. The probability values of the Sargan test indicate no rejection of the null hypothesis that the instruments as a group are exogenous. Therefore, the instruments used in each GMM model estimation are valid with appropriate exclusion restrictions.

5.1 Robustness test I: Alternative measure of green sustainability

Firstly, we re-estimated the model using Renewable Energy (percentage of total renewable electricity output) as a proxy for green sustainability, which we term green energy production. Renewable electricity (mainly hydropower) constitutes SSA's most significant share of renewable energy supply (Abeka et al., 2022).

From the results in Table 3, our robustness analysis indicates a positive coefficient of the effect of financial inclusion on renewable energy production. The coefficient associated with financial inclusion shows that increasing financial inclusion levels is essential in promoting renewable energy production. In this respect, the impact of financial inclusion can be attributed to the substantial capital investment required to develop and implement renewable energy technologies and systems. Most households struggle to afford the upfront costs of installing clean energy systems (Harris, 2019). As such, the increased availability of financial resources contributes significantly to promoting, adopting, and expanding renewable energy production through broader initiatives. Our result is consistent with the findings of (Ofosu-Mensah Ababio et al., 2023; Li et al., 2022). Financial inclusion enables the renewable energy industry to access better financial investment, showing the essential characteristics of green finance as outlined by Zhou et al. (2023), which is necessary to develop green energy initiatives.

5.2 Robustness test II: Single alternative measures of financial Inclusion and green sustainability

We re-estimated our results using various individual measures of environmental pollution (CO2, N2O, CH4, PM 2.5) as a dependent variable and used various individual measures of financial inclusion as the regressors. Given the use of highly aggregated data, our robustness approach helps to identify the mechanisms through which financial inclusion impacts emissions and the magnitude of estimated effects. We present our results in Table 4. Our findings indicate that ATMs contribute to increased levels of environmental pollution in SSA. Their contribution is evidenced by a positive coefficient associated with nitrous oxide and methane emissions. This observation could be linked to increased economic activities enabled by improved financial accessibility, which can increase emission releases (Liu et al., 2022). The presence of bank branches is linked to a reduction in nitrous oxide and methane emissions, but on the other hand, it contributes to an increase in CO2 emissions. This finding is consistent with Liu et al. (2022), who noted a small percentage impact of bank branches on carbon emission increase.

As seen from Table 4, bank credit enhances environmental sustainability by reducing the release of nitrous oxide and CO2 emissions across various activities. This result is intuitively correct since access to bank credit enables businesses to invest in clean energy projects, technologies and practices that may result in lower pollution (Zheng et al., 2023). Our results show that bank deposits are associated with lower pollution levels, as evidenced by negative coefficients with CO2, nitrous oxide, and methane emissions. Higher deposits could indicate a greater propensity for saving and a reduced need for immediate consumption, resulting in lower overall resource consumption and, subsequently, lower emissions. Moreover, banks may have substantial financing as deposits increase to support sustainable projects promoting environmental sustainability.

Further analysis highlights the positive impact of life insurance in reducing environmental pollution, particularly in mitigating methane and air pollution. The results suggest that individuals with life insurance coverage tend to adopt practices or behaviours leading to reduced pollution. Conversely, non-life insurance, mainly covering assets and properties, contributes to increased environmental pollution, as indicated by the positive coefficient on methane and PM2.5 emissions. We can infer that non-life insurance may indirectly incentivise behaviours or practices that lead to environmental pollution.

Our results suggest that ATMs and non-life insurance may hinder environmental sustainability within financial inclusion. These findings align with their impact on pollutants that primarily impact climate change (CO2, N2O, CH4) (as discussed in Sub-section 5.3), except for bank branches, which exhibit varying influences on specific pollution components. We further highlight that bank deposits, bank credit and life insurance play a beneficial role in reducing pollution levels.

5.3 Pls Robustness test III: Climate Footprint Index as a measure of green sustainability

Finally, as another measure of green sustainability, we focused on pollutants that primarily impact climate change (CO2, N2O, CH4) as a dependent variable. The results, outlined in Table 5, consistently support our initial findings, indicating that financial inclusion contributes to environmental pollution, as indicated by the climate footprint index. Specifically, we show that

ATMs, bank branches, and non-life insurance contribute to heightened levels of environmental pollution. The increase in these variables often signifies the expansion of industrialisation and infrastructure development, which jointly contribute to environmental pollution and the release of emissions through both direct and indirect mechanisms (Liu et al., 2022). On the other hand, bank credit, bank deposits, and life insurance play a vital role in reducing environmental pollution in the SSA. This observation is intuitively straightforward, as these variables are expected to provide credit to facilitate the adoption of green technologies and practices, and even reduce the long-term impact of environmental hazards.

Upon completing our robustness test, the results from the robustness analysis are not materially different from our baseline results. The results emphasise the reliability of our methodology, as they remain consistent even when alternative variables are employed to measure green sustainability and financial inclusion.

6. Conclusion and Policy Implications

We explored the relationship between financial inclusion and green sustainability in Africa and its link to environmental challenges. This relationship can have positive or negative effects. While it enables investments in green technologies and eco-friendly practices, it can also promote carbon emissions and energy-intensive consumption. In order to understand this relationship better, we developed three hypotheses to address the research objective better. We used a comprehensive empirical analysis spanning 38 Sub-Saharan African (SSA) countries from 2000 to 2021. We further developed an environmental pollution index and a financial inclusion index to account for the several dimensions of both variables. We also used the System GMM dynamic panel data estimation to address endogeneity and potential reverse causality issues.

Our results align with the notion that financial inclusion facilitates more accessible access to funds, fueling swift expansions in infrastructure, urbanisation, and increased energy consumption. However, this poses a significant risk of environmental degradation and a surge in waste generation. We found the presence of intra-regional heterogeneity within SSA. Southern Africa and Western Africa exhibit lower pollution levels than Eastern Africa. The variation suggests diverse regional strategies potentially influenced by varying financial inclusion and geographical factors. Our analysis's empirical findings also strongly support an inverted U-shaped relationship, consistent with the Environmental Kuznets Curve (EKC) hypothesis. We highlight the need to strike a balance in expanding financial services, emphasising the importance of reaching an optimal level of financial inclusion for fostering sustainable practices in the region. Perhaps we can conclude that the promotion of green sustainability tends to be more feasible for those with ample financial resources. Cultivating a culture of environmental awareness requires access to a diverse range of funds at an optimal level.

It is conventional to suggest that governments should continue promoting financial inclusion initiatives and encourage financial institutions to integrate environmental criteria into their lending policies and risk assessment processes. By incorporating sustainability considerations into their decision-making, financial institutions can incentivise businesses to adopt eco-friendly practices and prioritise investments in green technologies and projects. Such a policy may enable financial inclusion to be environmentally beneficial rather than unfavourable. It may involve providing incentives, subsidies, or reduced interest rates for loans and investments related to eco-friendly technologies like green bonds, green loans, green funds, and Sustainability-linked loans (SLLs). It is also worth noting that developing green credit score models that can evaluate financial institutions and their role in financing green sustainable projects compliance helps them get their commitment to financing and developing innovative products to guide investors toward genuinely eco-friendly initiatives. Lastly, policymakers are encouraged to develop long-term sustainability education and awareness programs tailored to different stages of financial inclusion. Recognising the U-shaped relationship between financial inclusion and green sustainability, they could focus on establishing basic environmental standards and gradually introduce more stringent regulations as financial inclusion progresses, ensuring that sustainable practices are integrated into business operations at an optimal stage of development. The financial market will also gradually respond to the opportunities embedded within these regulations. Strengthening environmental policies can potentially relocate capital towards green private sector investment, establishing a win-win benefit for all (Kruse et al., 2023).

Further research could assess the political and economic institutions that affect green sustainability in Sub-Saharan Africa and provide deeper insights into how certain factors, such as property rights and political stability, could impact green sustainability. Also, future research could assess this relationship at the micro-level to understand the behavioural aspects of individual financial inclusion levels and their impact on green sustainability.

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Tables

Table 1: Effect of Financial Inclusion on Environmental Pollution

	LINEAR	**NON-LINEAR (FII)**	**NON-LINEAR (GDP)**
Lag of Environmental Pollution Index	0.948***	0.898***	0.956***
	(0.000)	(0.000)	(0.000)
Financial Inclusion	0.052***	0.125***	0.049***
	(0.004)	(0.000)	(0.009)
Financial Inclusion_squared		-0.019***	
		(0.000)	
Economic Growth			0.014***
			(0.000)
Economic Growth_squared			-0.004***
			(0.000)
Controls			
Energy Use	0.050***	0.065**	0.061***
	(0.008)	(0.017)	(0.002)
Human Development	-0.011***	0.001	-0.009***
	(0.000)	(0.753)	(0.001)
Natural Resources	0.001	0.004*	0.004*
	(0.311)	(0.067)	(0.062)
Trade Openness	-0.001**	-0.005***	-0.000
	(0.047)	(0.000)	(0.269)
Economic Growth	0.009***	0.004***	
	(0.001)	(0.014)	
Government Expenditure	-0.023***	0.031***	-0.024***
	(0.002)	(0.000)	(0.000)
Urbanization	0.004**	0.005***	0.002
	(0.029)	(0.002)	(0.242)
Constant	0.289***	-0.444***	0.368***
	(0.001)	(0.000)	(0.000)
Diagnostics			
Wald Test	4280.39	27225.80	14173.76
Prob. (Wald)	0.000	0.000	0.000
AR1 (p-value)	0.231	0.227	0.224
AR2 (p-value)	0.365	0.363	0.363
Hansen-J (p-value)	0.592	0.316	0.548
Sargan (p-value)	0.347	0.285	0.439
DHT for instrument			
a. Instruments in levels			
H excluding group	0.242	0.625	0.267
b. IV (years, eq(diff))			
H excluding group	0.706	0.312	0.41
Number of groups	33	33	33
Number of instrumental	30	30	30
Observations	162	162	162

*Model 2 uses the financial inclusion index as a test of a non-linear pattern, while Model 3 utilizes GDP as a battery test of the typical EKC hypothesis. Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

Table 2: Intra-regional heterogeneity with respect to environmental pollution

	INTRA-REGIONAL
Lag of Environmental Pollution Index	0.720***
	(0.000)
Financial Inclusion in Southern Africa	-1.515***
	(0.000)
Financial Inclusion in Western Africa	-1.133***
	(0.000)
Controls	
Energy Use	-0.076***
	(0.001)
Human Development	-0.018***
	(0.007)
Natural Resources	-0.009***
	(0.003)
Trade Openness	-0.001
	(0.391)
Economic Growth	0.033***
	(0.000)
Government Expenditure	0.024***
	(0.008)
Urbanization	-0.003
	(0.541)
Constant	0.982***
	(0.000)
Diagnostics	
Wald Test	3544.37
Prob. (Wald)	0.000
AR1 (p-value)	0.217
AR2 (p-value)	0.368
Hansen-J (p-value)	0.338
Sargan (p-value)	0.252
DHT for instrument	
a. Instruments in levels	
H excluding group	
b. IV (years, eq(diff))	
H excluding group	0.501
Number of groups	33
Number of instrumental	30
Observations	162

*Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

Robustness Tests

Table 3: Robustness Test I - Alternative measure of green sustainability

	RENEWABLE ENERGY
Lag of Renewable Energy	0.996***
	(0.000)
Financial Inclusion	1.112***
	(0.000)
Controls	
Energy Use	0.852*
	(0.069)
Human Development	0.272***
	(0.001)
Natural Resources	0.379***
	(0.000)
Trade Openness	0.049**
	(0.029)
Economic Growth	-0.454
	(0.000)
Government Expenditure	-0.347***
	(0.010)
Urbanization	-0.300***
	(0.001)
Constant	7.615***
	(0.004)
Diagnostics	
Wald Test	59401.87
Prob. (Wald)	0.000
AR1 (p-value)	0.045
AR2 (p-value)	0.337
Hansen-J (p-value)	0.260
Sargan (p-value)	0.754
DHT for instrument	
a. Instruments in levels	
H excluding group	0.244
b. IV (years, eq(diff))	
H excluding group	0.226
Number of groups	30
Number of instrumental	33
Observations	217

*Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

Table 4: Robustness Test II - Single alternative measures of financial inclusion and green sustainability

	CO2 EMISSION	N2O EMISSION	METHANE	PM2.5
Lag of environmental pollutants	0.946***	0.767***	0.847***	0.789
	(0.000)	(0.000)	(0.000)	(0.000)
ATMs	-0.002*	0.003**	0.006***	-0.044
	(0.091)	(0.018)	(0.000)	(0.258)
Bank Branches	0.013***	-0.014**	-0.013***	0.231
	(0.000)	(0.028)	(0.001)	(0.290)
Bank Credit to Deposit	-0.002***	-0.002**	-0.002	0.004
	(0.000)	(0.034)	(0.124)	(0.941)
Bank Deposit	-0.005***	-0.005**	-0.006***	-0.158
	(0.000)	(0.024)	(0.001)	(0.233)
Life Insurance	0.035***	-0.043	-0.076***	-3.461**
	(0.007)	(0.149)	(0.000)	(0.046)
Non-Life Insurance	0.012	0.120	0.182***	9.819***
	(0.719)	(0.254)	(0.004)	(0.009)
Controls				
Energy Use	0.047***	0.055**	0.038***	1.557
	(0.000)	(0.048)	(0.007)	(190)
Human Development	0.010***	0.005	0.005*	0.438**
	(0.000)	(0.127)	(0.058)	(0.034)
Natural Resources	0.001	-0.004*	-0.011***	0.269***
	(0.436)	(0.062)	(0.001)	(0.009)
Trade Openness	0.002**	0.002**	0.004***	-0.151**
	(0.034)	(0.051)	(0.004)	(0.034)
Economic Growth	0.002**	0.013***	0.002***	-0.122
	(0.024)	(0.009)	(0.000)	(0.459)
Government Expenditure	-0.003	-0.011***	-0.012***	0.691*
	(0.506)	(0.002)	(0.001)	(0.089)
Urbanization	-0.004***	0.003	0.005**	-0.187*
	(0.000)	(0.225)	(0.017)	(0.069)
Constant	0.188***	0.232	0.028	7.289
	(0.000)	(0.117)	(0.882)	(0.127)
Diagnostics				
Wald Test	229058.02	22100.00	51748.76	2585.89
Prob. (Wald)	0.000	0.000	0.000	0.000
AR1 (p-value)	0.068	0.273	0.272	0.041
AR2 (p-value)	0.559	0.304	0.302	0.110
Hansen-J (p-value)	0.790	0.864	0.454	0.937
Sargan (p-value)	0.218	0.124	0.109	0.966
DHT for instrument				
a. Instruments in levels				
H excluding group	0.279	0.512	0.601	0.372
b. IV (years, eq(diff))				
H excluding group	0.755	0.911	0.5811	0.918
Number of groups	34	34	34	33
Number of instruments	30	34	34	30
Observations	289	289	289	162

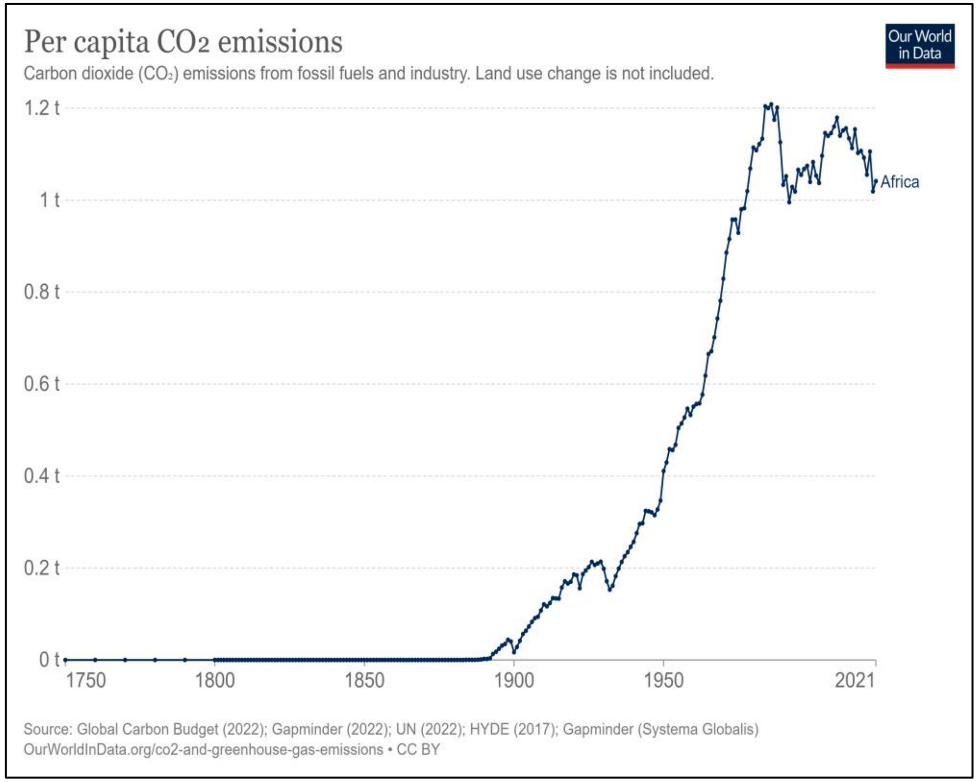
*Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

Table 5: Robustness Test III - Climate Footprint Index as a measure of green sustainability

	CLIMATE FOOTPRINT INDEX (1)	CLIMATE FOOTPRINT INDEX (2)
Lag of Climate Change Index	0.763***	0.677***
	0.000	(0.000)
Financial Inclusion	0.071***	
	(0.000)	
ATMs		0.005***
		(0.006)
Bank Branches		0.023**
		(0.025)
Bank Credit to Deposit		-0.007***
		(0.009)
Bank Deposit		-0.019***
		(0.003)
Life Insurance		-0.271***
		(0.000)
Non-Life Insurance		0.654***
		(0.000)
Controls		
Energy Use	0.044***	0.132***
	(0.000)	(0.007)
Human Development	-0.013***	0.018
	(0.000)	(0.141)
Natural Resources	-0.015***	-0.010**
	(0.000)	(0.040)
Trade Openness	0.004***	0.002
	(0.000)	(0.297)
Economic Growth	0.025***	0.021***
	(0.000)	(0.011)
Government Expenditure	-0.047***	-0.048***
	(0.000)	(0.001)
Urbanization	-0.001	-0.008
	(0.609)	(0.270)
Constant	0.580***	1.182***
	(0.000)	(0.010)
Diagnostics		
Wald Test	20558.89	30400.00
Prob. (Wald)	0.000	0.000
AR1 (p-value)	0.279	0.262
AR2 (p-value)	0.305	0.304
Hansen-J (p-value)	0.847	0.534
Sargan (p-value)	0.183	0.238
DHT for instrument		
a. Instruments in levels		
H excluding group	0.401	0.254
b. IV (years, eq(diff))		
H excluding group	0.875	0.623
Number of groups	34	34
Number of instruments	34	34
Observations	289	289

*Model 1 uses the financial inclusion index as a regressor, while Model 2 utilizes individual financial inclusion indicators. Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

Figures



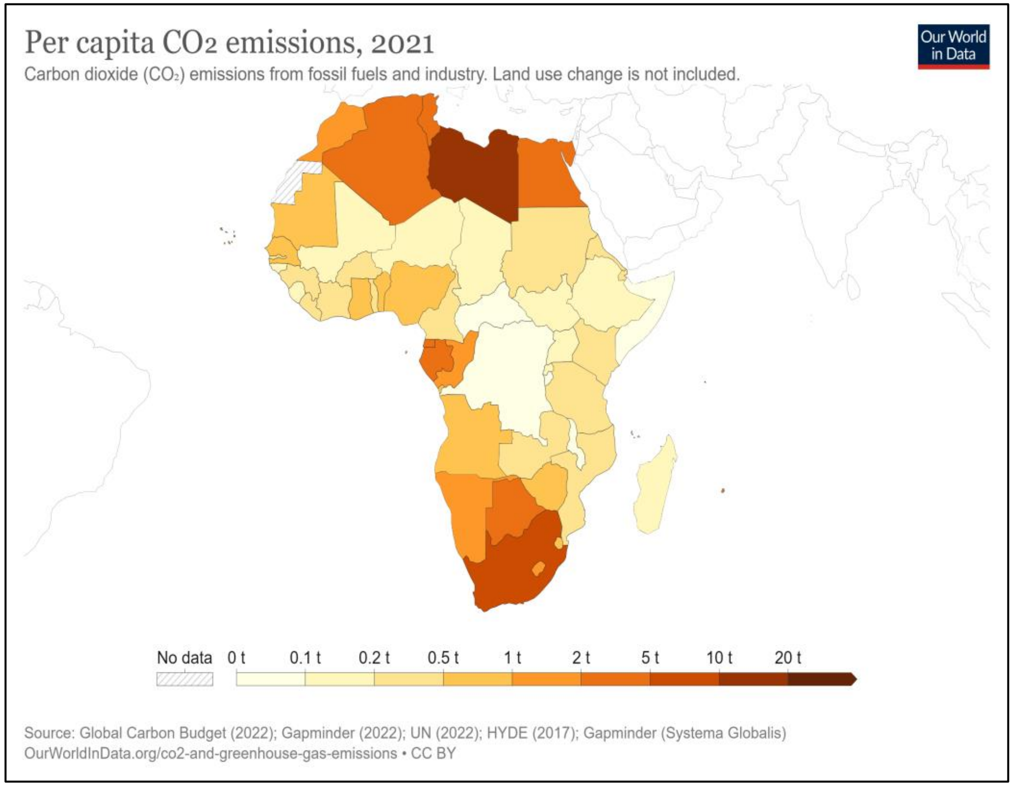


Fig. 1: Carbon emission trend in Africa
Source: Our World in Data

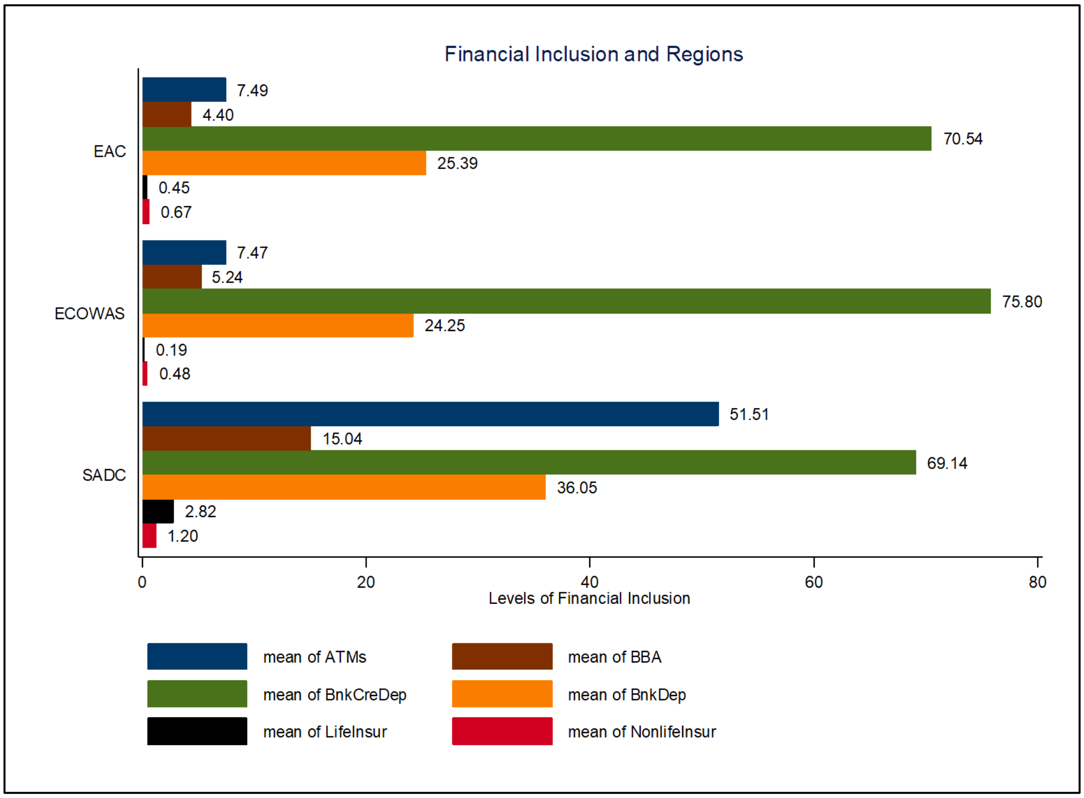


Fig. 2 Intra-Regional Financial Inclusion Comparison
Source: Global Financial Development Database, 2000-2021

Appendix

Table A1: List of the sample of 38 Sub-Saharan (SSA) economies

SUB-SAHARAN AFRICA COUNTRIES	
Eastern Africa	**Western Africa**
Burundi	Benin
Congo	Burkina Faso
Congo Republic	Cape Verde
Kenya	Cameroon
Madagascar	Chad
Mauritius	Cote d’Ivoire
Mozambique	Gabon
Rwanda	The Gambia
Sudan	Ghana
Tanzania	Guinea
Uganda	Mali
	Mauritania
Southern Africa	Niger
Angola	Nigeria
Botswana	Senegal
Eswatini	Sierra Leone
Lesotho	Togo
Malawi	
Namibia	
Seychelles	
South Africa	
Zambia	
Zimbabwe	

Table A2: Description of variables and measurement

Variable	Measurement	Data Source
Environmental Pollution Index	Principal Component Analysis of four (4) variables: CO2 emission, PM 2.5, Methane emission, Nitrous oxide emission	See Appendix Table A3
Financial Inclusion Index	Principal Component Analysis of six (6) variable estimates measuring access, usage, and quality of product	See Appendix Table A4
Energy Use	Per capita electricity generation from oil (kWh)	Our World in Data
Human Development	School enrollment, Tertiary	World Development Indicators 2000 - 2021
Trade Openness	Sum of exports and imports of goods and services as a share of gross domestic product.	World Development Indicators 2000 - 2021
Natural Resource Dependency	Total national resource rents (% of GDP)	World Development Indicators 2000 - 2021
Economic Growth	Gross Domestic Product (GDP) (% growth)	World Development Indicators 2000 - 2021
Government Expenditure	Annual percentage growth of general government final consumption expenditure (% of GDP)	World Development Indicators 2000 - 2021
Urbanisation	Urban Population (% of total population)	World Development Indicators 2000 - 2021

Table A3: Component variables of the Environmental Pollution Index

Components	Individual indicator(s)	Source of Data
CO2 emissions	CO2 emission per capita (metric tons)	World Development Indicators 2000 – 2021
Particulate Matter (PM) 2.5	PM 2.5 (particles with a diameter of 2.5 micrometres or less)	World Development Indicators 2000 – 2021
Methane emissions	Methane emission (metric tons of CO2 equivalent per capita)	World Development Indicators 2000 – 2021
Nitrous oxide emission	Nitrous oxide emission (metric tons of CO2 equivalent per capita)	World Development Indicators 2000 – 2021

Table A4: Component variables of the Financial Inclusion Index

Components	Individual indicator(s)	Source of Data
ATM per 100,000 adults	Number of ATMs per 100,000 adults.	Global Financial Development, 2000-2021
Bank Branches per 100,000 adults	Number of commercial bank branches per 100,000 adults.	Global Financial Development, 2000-2021
Bank Deposits	Money deposited in banks as a share of GDP.	Global Financial Development, 2000-2021
Bank Credit to Bank Deposit	Credit provided by domestic money banks as a share of total deposits.	Global Financial Development, 2000-2021
Life Insurance Premium	Ratio of life insurance premium volume to GDP.	Global Financial Development, 2000-2021
Non-Life Insurance Premium	Ratio of non-life insurance premium volume to GDP	Global Financial Development, 2000-2021

Table A5 - Estimation results of the principal component analysis

Eigenvalue of the correlation matrix				**Eigenvectors of the first component**	
Component no.	**Eigenvalue**	**Eigenvalue Difference**	**Cumulative percentage of total variance**	**Variables**	**Eigenvector**
(a) Environmental Pollution Index					
1	1.649	0.310	0.412	CO_2 emission	0.237
2	1.338	0.692	0.747	Particulate Matter (PM) 2.5	0.301
3	0.646	0.280	0.909	Methane emissions	0.674
4	0.366		1.000	Nitrous oxide emission	0.632
(b) Financial Inclusion Index					
1	3.956	3.000	0.659	ATMs	0.450
2	0.953	0.347	0.818	BBA	0.449
3	0.606	0.292	0.919	Bank credit to Bank deposit	0.221
4	0.314	0.193	0.971	Bank Deposit	0.365
5	0.120	0.068	0.991	Life Insurance	0.451
6	0.052		1.000	Non-life Insurance	0.458

Table A6: Descriptive statistics

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
Environmental Pollution Index (EPI)	380	0	1.284	-1.438	7.567
Renewable Energy	608	48.575	36.290	0	100
Financial Inclusion Index (FII)	427	0	1.989	-2.083	9.120
Energy Use	814	193.607	624.345	0	5352.816
Human Development	537	8.637	7.691	0.318	43.959
Trade Openness	805	71.161	35.800	0.757	225.023
Natural Resource	836	10.761	10.435	0.002	59.684
GDP Growth	836	4.012	4.573	-20.599	33.629
Government Expenditure (GE)	769	15.140	6.907	0.952	43.484
Inflation	798	10.431	36.763	-16.860	557.202
Urbanisation	836	39.564	16.562	8.246	90.423

Table A7: Pairwise correlations analysis

	Environmental Pollution Index	Renewable Energy	Financial Inclusion	Energy Use	Human Development	Trade	Natural Resource	Economic Growth	Gov't Expenditure	Urbanization
Environmental Pollution Index	1.000									
Renewable Energy	-0.165	1.000								
Financial Inclusion	0.129	-0.301	1.000							
Energy Use	0.054	-0.147	0.201	1.000						
Human Development	0.162	-0.193	0.534	0.218	1.000					
Trade	0.006	-0.092	0.315	-0.244	0.250	1.000				
Natural Resources	-0.065	0.196	-0.264	-0.223	-0.279	-0.007	1.000			
Economic Growth	0.070	0.034	-0.160	-0.125	-0.208	0.086	0.153	1.000		
Gov't Expenditure	0.081	0.143	0.314	-0.175	0.163	0.503	-0.212	-0.095	1.000	
Urbanization	0.265	-0.280	0.467	0.238	0.512	0.399	0.032	-0.167	0.140	1.000

**significance at 10% level; **significance at 5% level; ***significance at 1% level*

Table A8: Effect of Financial Inclusion on Environmental Pollution - based on alternative sets of instruments

	LINEAR	NON-LINEAR (FII)	INTRA-REGIONAL
Lag of Environmental Pollution Index	0.949***	0.766***	0.694***
	(0.000)	(0.000)	(0.000)
Financial Inclusion	0.016*	0.409***	0.117***
	(0.062)	(0.000)	(0.001)
Financial Inclusion_squared		-0.048***	
		(0.000)	
Financial Inclusion in Southern Africa			-1.022***
			(0.000)
Financial Inclusion in Western Africa			-0.992***
			(0.000)
Controls			
Energy Use	0.024	-0.052**	-0.046*
	(0.118)	(0.004)	(0.055)
Human Development	0.003*	-0.022***	-0.016**
	(0.098)	(0.000)	(0.004)
Natural Resources	0.001	0.014***	-0.001
	(0.307)	(0.000)	(0.910)
Trade Openness	-0.001**	-0.012***	-0.001
	(0.053)	(0.000)	(0.420)
Economic Growth	0.006**	0.003	0.024**
	(0.002)	(0.192)	(0.003)
Government Expenditure	-0.024***	0.031***	-0.003
	(0.000)	(0.000)	(0.823)
Urbanisation	0.003**	0.019***	-0.002
	(0.026)	(0.000)	(0.568)
Constant	0.284***	-0.111	1.039***
	(0.000)	(0.487)	(0.000)
Diagnostics			
Wald Test	10498.07	93763.17	1988.30
Prob. (Wald)	0.000	0.000	0.000
AR1 (p-value)	0.229	0.221	0.217
AR2 (p-value)	0.369	0.343	0.365
Hansen-J (p-value)	0.613	0.505	0.377
Sargan (p-value)	0.310	0.220	0.216
DHT for instrument			
c. Instruments in levels			
H excluding group	0.256	0.369	
d. IV (years, eq(diff))			
H excluding group	0.573	0.482	0.440
Number of groups	33	33	33
Number of instrumental	30	30	30
Observations	162	162	162

*Statistical significance at the 1%, 5%, and 10% level is indicated by ***, **, and *, respectively*

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