The Role of Energy Equity and Income Inequality in Environmental Sustainability

Ofori, Pamela E. and Ofori, Isaac K. and Annan, Kenneth

University of Insubria, National University of Ireland Maynooth, Oregon State University

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Pamela E. Ofori[a*]
**Corresponding Author*
[a]Department of Economics, University of Insubria,
Via Monte Generoso 71, 21100, Varese, Italy.
E-mail: peofori@outlook.com
ORCiD: https://orcid.org/0000-0002-9952-3586

Isaac K. Ofori[b]
[b]School of Business, National University of Ireland Maynooth,
Maynooth, Co. Kildare, W23 WK26, Ireland.
Email: ikofori@outlook.com
ORCID: https://orcid.org/0000-0002-0591-1271

Kenneth Annan[c]
[c]Department of Applied Economics, Oregon State University,
Ballard Hall, 2591 SW Campus Way, Corvaliis, OR, USA.
E-mail: annank@oregonstate.edu

Abstract

Progress in energy equity, income equality, and environmental quality are fundamental to sustainable development. However, studies providing evidence-based recommendations concerning the joint effect of energy equity and income inequality on environmental sustainability in Africa are lacking. This study fills this gap by using a panel dataset covering 41 African countries from 2008-2019. Results from the Driscoll-Kraay standard errors and the dynamic system GMM estimators reveal the following: (1) energy equity promotes environmental quality, whereas income inequality hampers it, and (2) income inequality nullifies the favourable environmental gains of energy equity. These findings remain consistent when we use the ecological footprint as an alternative measure of environmental quality. We conclude that addressing income inequality is essential for ensuring that energy equity enhances environmental quality. Policymakers should prioritise energy equity and fairer income distribution initiatives to achieve sustainable development goals.

Keywords: Africa; Energy equity; Environmental quality; Income inequality

JEL Codes: D31; O13; O55; Q40; Q5; Q53

1. Introduction

Access to clean, modern, and affordable electricity and energy-saving technologies is fundamental for sustainable development (Ofori & Batuo, 2024; Ofori et al., 2023). Despite the remarkable role of energy consumption in economic growth, fossil fuels have been identified as significant contributors to environmental degradation, global warming, and climate change (International Energy Agency [IEA], 2023; Adom et al., 2021). Accordingly, SDG 7 stresses that access to affordable, reliable, sustainable, and modern energy is vital to environmental sustainability. Empirical contributions in this direction are timely, considering recent reports that each year, almost a million people in Africa die from air pollution and greenhouse gasses (Global Green Growth Institute, 2019, p.3).

Accordingly, in this study, we pay attention to the role of energy equity and income inequality in Africa's pursuit of environmental sustainability. We consider the former as per information in IEA (2022), which suggests that inequalities in access to renewable energy and clean technologies for cooking are high in Africa when compared to other developing societies. For instance, the World Bank (2022) reports that over 600 million people in Africa (approximately 43% of the continent's total population) lack access to renewable electricity. The report further indicates that 74% of households in Africa rely heavily on firewood and wooden biomass as a source of energy for cooking and lighting, exposing them to toxic fumes. Additionally, whereas at least 80% of the continent's urban population has access to renewable electricity and clean cooking technologies, only 26% of their counterparts in rural communities have access to electricity (IEA, 2022).

The study argues that widespread inequalities in electricity access across the rural-urban divide can hamper Africa's environmental sustainability agenda. It also brings to the fore the case for assessing the underlying socioeconomic issues hindering equitable energy access. This is where income inequality, which Chancel et al. (2023) estimate to be grave in Africa, deserves attention. On the one hand, high-income inequality often deprives many people of basic needs and resources, causing them to resort to using unclean energy (e.g., kerosene, fossil fuels, and biomass, and primitive cooking equipment/techniques (e.g., smoke-curing, ash-cooking and cooking pots), which have been shown to degrade the environment and intensify exposure to environmental health problems (Sarkodie & Adams, 2020a; Baloch et al., 2020; Galvin, 2020; Vornovytskyy & Boyce, 2010Asongu & Odhiambho, 2021). However, in societies with fairer income growth and distribution, there is universal access to clean cooking fuels and technologies. This can accelerate the adoption of electric cookers, energy-efficient stoves, and green technologies for both domestic and commercial purposes, contributing to forest conservation and air pollution and greenhouse gas emission mitigation (World Health Organization [WHO], 2018; Murshed, 2022; Dagnachew et al., 2020).

Although studies have assessed the impact of income inequality on renewable electricity access/consumption and the adoption of clean technologies for cooking in Africa (Asongu & Odhiambho, 2021; Sarkodie, & Adams, 2020a), there remains a significant research gap regarding how it affects environmental quality. Further, although it is known that income inequality can exacerbate environmental issues (Gimba et al., 2023; Ekeocha, 2021; Langnel et al., 2021; Balock et la., 2020), the specific interaction between energy equity and income inequality in influencing environmental quality remains unexplored. This study addresses these critical gaps in the scholarly literature by first constructing a comprehensive index for environmental quality based on macro data from 2008-2019 for a panel of 41 African countries.

This study makes three major contributions to the sustainability discourse. First, the measure of the environmental quality variable is comprehensive, as it captures both greenhouse gas emissions and air pollution. This means that we deviate from previous studies, such as those by Maji et al. (2022) and Alola et al. (2019), which focus solely on CO_2 emissions as a proxy for environmental quality. Second, we focus on energy equity proxied by rural-urban equality in access to electricity and clean cooking fuels and technologies. Most existing studies mainly use energy efficiency, energy consumption and energy usage (see e.g., Murshed., 2022; Khan et al., 2021; Jebli & Youssef, 2017), which do not provide a clear depiction of clean energy and its equal distribution of clean energy. Third, we examined the unconditional and conditional effects of energy equity and income inequality on environmental quality.

The rest of the paper is organised as follows: Section 2 reviews the existing literature on energy equity, income inequality, and environmental quality, while Sections 3 and 4 present the methods and findings from the study. Section 5 summarises and offers policy recommendations.

2. Literature Review

2.1 Energy equity and environmental quality— Theoretical background

The theoretical link between energy equity and environmental quality is based on energy justice and just sustainability theories, as proposed by Sovacool and Dworkin (2015) and Agyeman et al. (2003), respectively. First, energy justice theory is a framework that emphasises that the benefits and burdens of energy systems are fairly and equitably distributed. This theory also stresses the intersection between social inequalities and environmental injustices, emphasising the need for an equitable distribution of environmental benefits and burdens. In the context of energy equity, this theory suggests that addressing disparities in energy access and environmental quality is essential to achieving energy justice and ensuring fair treatment for all communities (McCauley & Heffron, 2018; Jenkins et al., 2016; Mohai et al., 2009; Schlosberg, 2004; Bowen, 2002). In other words, energy justice is related to environmental quality by providing a comprehensive framework for developing energy policies and practices that are both socially just and environmentally sustainable.

For instance, the installation of solar panels on rooftops and community spaces can provide broader access to clean energy, and this reduces heavy reliance on traditional energy sources, which are non-renewable, leading to lower greenhouse gas emissions, carbon emissions and improved environmental quality (Peters et al., 2018). Kenya has seen improvement in indoor air quality because of the adoption of the M-KOPA solar energy since 2010, which offers affordable off-grid solar home systems on a pay-as-you-go basis and makes clean energy accessible to low-income households. Some Eastern African countries have also adopted this initiative, and this has enhanced indoor air quality (M-KOPA Solar, 2024; Trotter, 2016).

Second, the just sustainability theory integrates principles of social justice and environmental sustainability, emphasising the interconnectedness between social equity, environmental protection, and economic development. This theory calls for transformative change that addresses social inequalities and environmental degradation simultaneously, recognising that sustainable development must be inclusive and equitable. A practical initiative that incorporates the principles of just sustainability is the Green Belt Movement (GBM) in Kenya, founded by Wangari Maathai in 1977. The GBM is into planting millions of trees across Kenya to avoid deforestation and restore biodiversity.

This action addresses environmental sustainability while promoting social justice and empowering the impoverished (Muhonja, 2023). In the context of energy equity, just sustainability theory underscores the importance of ensuring access to clean and affordable energy for all communities while minimising environmental impacts and promoting social well-being (Agyeman, 2008). Based on the theoretical literature, the first hypothesis is formulated as follows:

Hypothesis 1: Energy equity enhances environmental quality.

2.3 Income inequality and environmental quality—Theoretical background

Several theories have been proposed to explain the complex relationship between income inequality and environmental quality. In this study, we focus on two, namely, the marginal propensity to emit (MPE) theory and the Veblen effect. The MPE theory suggests that the level of income inequality influences environmental degradation. For instance, in poorer economies, increasing income inequality could lead to more environmental degradation as these economies push for industrialisation to bridge the income gap (Baloch et al., 2020). Conversely, in developed countries, an increase in income inequality may reduce environmental degradation. This is because a decrease in the income inequality gap tends to increase the income of poorer households, who have a higher marginal propensity to emit, often through increased consumption of unclean energy resources, thereby reducing overall environmental quality (Baloch et al., 2020; Wan et al., 2022; Sager, 2019; Vornovytskyy & Boyce, 2010).

The Veblen effect posits that income inequality triggers 'status' consumption. The rich, aiming to maintain their standards and lavish lifestyle, engage in the conspicuous consumption of luxury goods. This status-driven consumption has been identified as a key factor linking income inequality to high CO_2 emissions (Schor, 1998). In sum, the MPE theory and Veblen effect contribute to understanding how income inequality is intricately related to CO_2 emissions, providing valuable insights into the complex dynamics between income inequality and environmental outcomes. Consistent with these theories, Hypotheses 1b and 2 are structured as follows:

Hypothesis 2: Income inequality hinders environmental quality.

Hypothesis 3: Income inequality conditions energy equity to degrade the environment.

2.4 Empirical literature on the effect of energy and environmental quality

Energy equity is a multifaceted concept that plays a crucial role in various aspects of the economy, including population, trade, income inequality, poverty, consumption, and the environment. While numerous studies have examined energy in the context of usage, access, consumption, and production in relation to environmental sustainability, the broader impact of energy equity on environmental quality remains a key area of interest. In the same way, Azimi and Rahman (2024) empirically assessed the effect of renewable energy on ecological footprint in 74 developing countries from 2000-2020. Employing the threshold regression, the authors find that under the threshold effect of fiscal capacity, human development, institutional quality, and population density, renewable energy reduces ecological footprint. Alola et al. (2019) also consider CO2 emissions as a measure of environmental quality and assess the role of renewable energy on environmental sustainability in 3 European Union countries from 1990-2016. Evidence based on the fully modified and dynamic ordinary least squares estimators shows that renewable energy consumption reduces CO2 emissions.

Following a similar narrative, Asongu et al. (2019) employed 40 African countries over the period 2002-2017 and found that renewable energy consumption increases environmental quality proxied by CO2 emissions using fixed effect and quantile regression. Salahuddin et al. (2020) also add to the empirical literature on the role of renewable energy in improving environmental quality, considering CO2 emissions as an indicator. Using a panel of 34 SSA countries over the period 1984 to 2016 and the second-order generation test, the authors show that renewable energy reduces CO2 emissions, whereas fossil fuel enhances it.

In a recent study comprising 41 SSA countries and macro data from 2008 to 2019, Maji et al. (2022) found empirical evidence that renewable energy consumption reduces CO_2 emissions using SYS-GMM. By employing the fully modified generalised least squares method, Kahn et al. (2021) investigated the effect of energy consumption on carbon emissions in ten Central European countries from 2005-2018. The authors found that fossil fuel consumption hampers environmental quality. Nabavi-Pelesaraei et al. (2021) used envelopment analysis and lifecycle assessment to show that optimising energy consumption mitigates environmental emissions in terms of agricultural activities.

In contrast, Jebli and Youssef (2017) applied the dynamic least squares estimator to a panel dataset from 1980-2011 and reported that renewable energy consumption intensifies CO_2 emissions in North African countries. We found similar evidence in Koçak et al. (2019), who reported that access to electricity and poverty degraded the environment in 48 SSA countries from 2010 to 2016. The literature review above only examined the impact of renewable energy consumption on CO2 and greenhouse gas emissions. Specifically, as economies emphasise the relevance of energy justice, emission reduction and environmental quality, it is prudent to examine the impact of energy equity on environmental quality; however, minimal studies have examined the energy energy-environmental quality nexus.

2.5 *Empirical literature on the effect of Income inequality on environmental quality*

Baek and Gweisah (2013) employ the autoregressive distributed lag technique and an annual dataset spanning 1967 to 2008 to examine the short- and long-term effects of income inequality on CO_2 emissions in the USA. This study finds that income equality promotes environmental quality in the U.S. in the short and long term. More recently, Dada et al. (2023) employed quantile regression and a panel of 29 African countries from 2000-2017 to demonstrate that income inequality increases environmental degradation in the 5th-30th quantile. However, from the 70th quantile onwards, income inequality decreases environmental degradation. Focusing on 32 SSA countries from 1995 to 2018, Gimba et al. (2023) found evidence based on the augmented Anderson–Hsiao estimator. The authors consider ecological footprint as a measure of environmental degradation and reveal that income inequality reduces environmental degradation.

In the context of developing countries, Baloch et al. (2020) also examined the nexus between income inequality and Co_2 emissions in 40 SSA countries for the period 2010-2016 using the Driscoll-Kraay standard error estimator. This study provides evidence that an increase in income inequality increases CO_2 emissions.

From the empirical review above, it is evident that numerous studies have considered only a single measure, like CO2 emissions and ecological footprint, as a measure of environmental quality. Moreover, proxies like greenhouse gas emissions, sulphur oxide, carbon monoxide, methane oxide and nitrous oxide are also used as proxies for environmental quality (Cho et al., 2014; Fodha & Zaghdoud, 2010). However, these proxies do not provide a comprehensive view of environmental quality. To fill this, we construct an index for environmental quality and assess how energy equity impacts it.

2.6 Conceptual Framework

Our conceptual framework draws on the aforementioned theoretical literature. Figure 1 shows the roots of air pollution and emission levels: (1) Co_2 emissions, which denote the release of carbon dioxide gas into the atmosphere; and (2) methane oxide, which is primarily emitted during *the* production and transport of coal, oil, livestock, agricultural practices, and natural gas; (3) nitrous oxide, which is a gas released from agricultural and industrial activities, synthetic fertilisers, and combustion of fossil fuels; (4) ambient air pollution, which is a particulate matter with a diameter of 2.5 (PM2.5) caused by vehicle exhaust, power plants, and wildfires; and (5) other greenhouse gas emissions, comprising hydrofluorocarbons (HFC), perfluorochemicals (PFC), and sulphur hexafluoride (SF6), which cause global warming and depletion of the ozone layer as well as health complications.

Furthermore, our framework shows that even though energy equity, which comprises access to clean electricity and clean cooking fuel and technologies, can increase environmental quality, income inequality can play a significant moderating role.

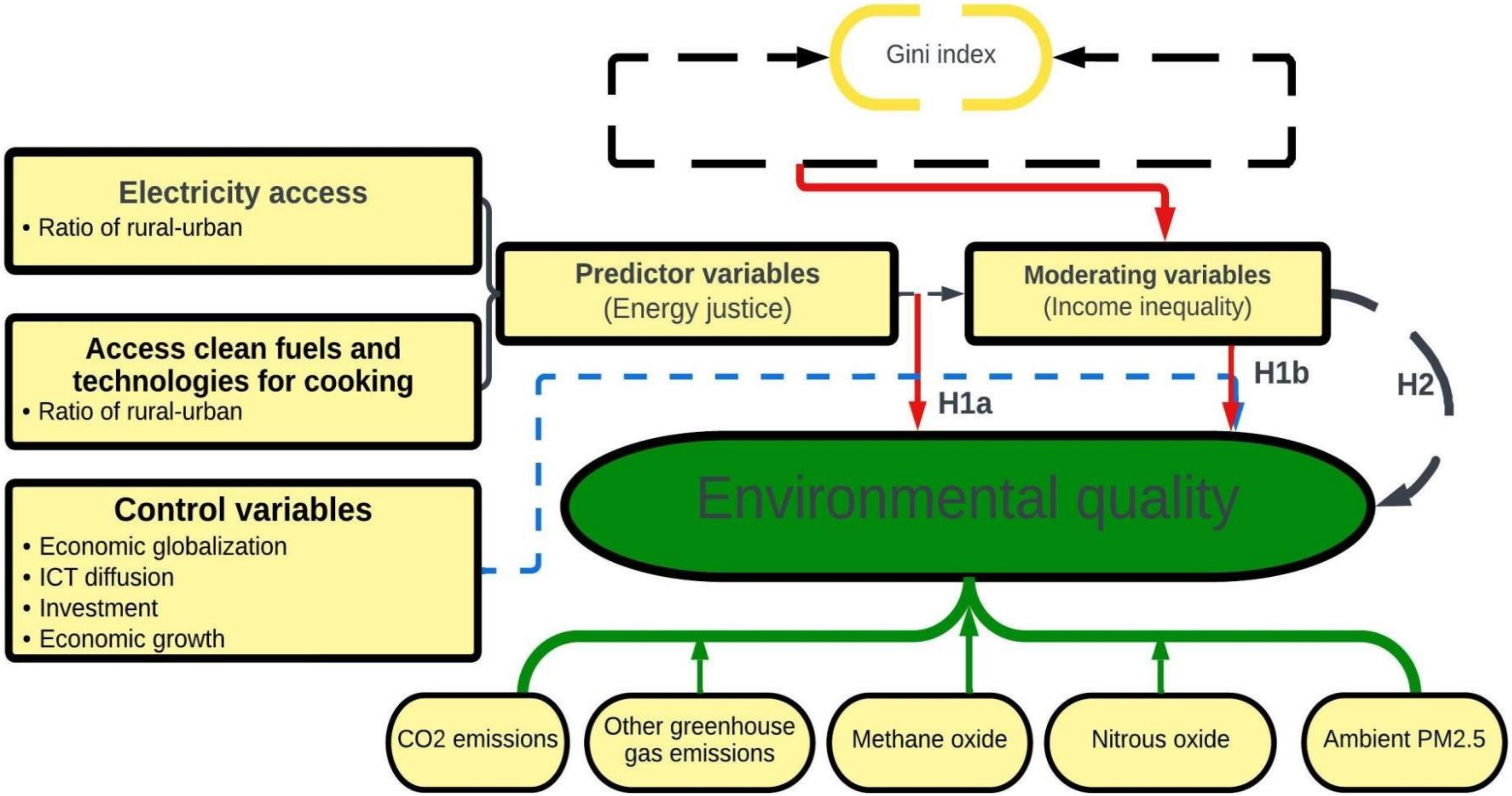

Figure 1: Analytical framework and transmission mechanism of energy equity and income inequality on environmental quality

3.0 Data and methodology

3.1 Data

To empirically examine the unconditional and conditional effects of energy equity on environmental quality, we focus on a panel of 41 African countries from 2008-2019. The choice of study period and countries was motivated by data availability. Countries such as Libya, South Sudan, Somalia, Djibouti, and Eritrea are excluded from this empirical analysis because they need more data. Table A.1 provides a list of sampled countries. The variables employed in this study are obtained from four sources, namely: the World Development Indicators [WDI] (World Bank, 2023), the World Income Inequality Database [WIID] (Solt, 2020), the KOF Globalisation Index [KOF index] (Gygli et al., 2019) and the African Infrastructure Knowledge Program [AIKP] (African Development Bank, 2018).

3.1.2 Outcome variable

The dependent variable is environmental quality, which is an index generated using the principal component analysis (PCA). The PCA is considered reliable in generating indices because of its ability to reduce dimensionality and collinearity among several variables to obtain a smaller set of indices, referred to as principal components (Yang et al., 2020). To this end, we employ five environmental quality variables, namely, CO_2 emissions (CO_2), nitrous oxide (Nit), methane (Meth), other green gas emissions (Ghgs) and ambient PM 2.5 (Amb) for the PCA.

These variables are intuitively relevant for calculating the environmental quality index because they include greenhouse gas emissions and air pollution (. Sinha et al., 2020). A detailed procedure for constructing the environmental quality index for the sampled countries is provided in Tables A.3 and A.4 and Figure A.1 in the Appendices section. To allow for robustness checks, we use an alternative dependent variable, the ecological footprint, measured in hectares per capita of degraded natural capital. The ecological footprint variable is a good measure of environmental quality because it considers the deterioration of grazing land, cropland, forestland, fishing grounds, built-up land, and the carbon footprint for human needs (Destek & Sarkodie, 2019). Data for ecological footprint are taken from the Global Footprint Network (2023).

3.1.3 Main Predictor Variable

The main predictor variable of interest is energy equity (EE). We follow prior contributions such as Müller et al. (2021) by capturing EE as (i) distributional justice [EE_1] (proxied by rural-urban equality in access to electricity) and procedural justice [EE_2] (proxied by rural-urban equality in clean cooking fuel and technology usage). We compute EE_1 as the ratio of rural access to electricity to urban access to electricity. Similarly, EE_2 was calculated by taking the ratio of rural access to clean cooking fuel and technologies to urban access to clean cooking fuel and technologies. All the energy variables were obtained from the WDI (World Bank, 2023).

3.1.4 Moderating variable

The moderating variable is income inequality, captured by the Gini index. The index indicates the distribution of income in a country. It ranges from 0, indicating a case of perfect inequality, to 1, denoting a situation where there is absolute income inequality. We pay attention to income inequality because the distribution of income in the population has implications for (i) switching to renewable energy, such as hydroelectricity; (ii) adopting clean fuels and technologies; and (iii) participating in formal/informal economic activities. Income inequality data are taken from the WIID (Solt, 2020).

3.1.5 Control variables

The control variables used in this study are total population, domestic investment, trade openness, GDP per capita, employment, and information [ICT] diffusion. Foremost, we consider domestic investment since it affects the environmental performance of firms and industries. For instance, investing in cleaner production technologies can reduce greenhouse gas emissions (Ikram et al., 2021). Domestic investment is proxied by gross fixed capital formation as a share of GDP. We obtain the data from the World Bank (2023).

We focus on population, proxied by the percentage of the total population, because it has a massive impact on ecological footprint. For example, high population growth can trigger high energy consumption and ecosystem destruction for accommodations, farming, and businesses (Cole & Neumayer, 2004). Also, our focus on employment stems from increased economic activity and disposable income. Evidence shows that rising income levels can enable the masses to acquire energy-efficient materials for production and consumption. This can contribute to high CO_2 emissions, particularly if the share of fossil fuels in the overall energy mix is high (Achuo et al., 2023). Both population and employment are drawn from the World Bank (2023). Furthermore, we focus on trade openness because previous studies have shown that greater integration into the global market can intensify environmental quality and greenhouse gas emissions or accelerate the spread of green technologies for green growth (Ofori & Figari, 2023). The trade openness data are taken from the World Bank (2023).

Moreover, ICT diffusion deserves attention in environmental quality analysis for two reasons. Previous studies have shown that ICT diffusion promotes innovation, which mitigates ecological footprints (Kabanda, 2011). Previous studies have also reported that ICT diffusion triggers setbacks in environmental quality by intensifying greenhouse gas emissions (Verma et al., 2023). Finally, we also included GDP per capita as a determinant of environmental quality. Although rising GDP per capita can accelerate environmental degradation, it can also enhance eco-innovation and environmental stewardship (UNEP, 2011, p.17). Table 1 provides a detailed description and summary of the variables.

Table 1: Variable definitions and summary statistics, 2008-2019

Variables	Symbol	Definitions	Data sources	N	Mean	S. Dev	Min	Max
Outcome variables								
Environmental Quality	Envt	Index generated using the principal component analysis	The authors	492	0.016	1.034	-0.497	6.118
Ecological footprint		Measures the ecological assets that a given population or product requires to produce the natural resources it consumes (including plant-based food and fibre products, livestock and fish products, timber and other forest products, and space for urban infrastructure) and to absorb its waste, especially carbon emissions.	Global Footprint Network (2023)	492	1.4140	0.683	0.000	4.024
Main predictor variables								
Energy equity 1	EE_1	The ratio of rural population with access to electricity to urban population with to electricity.	World Bank (2023)	434	0.306	0.260	0.0113	1.036
Energy equity 2	EE_2	The ratio of rural population with access to clean fuels and technologies for cooking to urban population with access to clean fuels and technologies for cooking,	World Bank (2023)	492	0.1919	0.203	0.000	1.000
Moderating variable								
Gini index	Gini	Measures the extent to which the distribution of income among individuals or households within an economy deviates from a perfect equality	Solt (2020)	492	46.934	7.864	34.400	72.300
Control variables								
Population	Topt	Urban population as a percentage of total population	World Bank (2023)	492	54.914	4.607	47.183	70.775
Employment	Lfpr	The labour force participation rate is the ratio between the total labour force divided by the total working-age population in percentage.	World Bank (2023)	492	68.179	10.905	43.630	90.340
Trade openness	Trade	the sum of exports and imports of goods and services (% GDP).	World Bank (2023)	492	65.489	32.635	0.000	179.121
ICT diffusion	Ictdif	Composite index for the construction, extension, improvement, operation, and maintenance of communication systems (postal, telephone, telegraph, wireless, and satellite communication systems).	AfDB (2018)	492	6.4940	8.504	0.0013	58.904
Domestic investment	Dinvt	Gross fixed capital formation (% of GDP)	World Bank (2023)	492	7.008	22.830	-65.68	239.83
GDP per capita	Gdppc	GDP per capita, PPP (constant 2017 international $)	World Bank (2023)	492	4187.11	4294.9	751.66	22870.2
PCA variables								
CO_2 emissions	CO_2	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement (metric tons per capita).	World Bank (2023)	492	1467.62	7185.9	-18330.7	54698.2
Other greenhouse gas emissions	Ghgs	Other greenhouse gas emissions, hydrofluorocarbons (HFC), perfluorocarbon (PFC) and. sulphur hexafluoride (SF6) (thousand metric tons of CO2 equivalent)	World Bank (2023)	492	35.7288	14.202	14.3464	94.0538
Methane oxide	Meth	Methane oxide emissions in thousand metric tons of CO2 equivalent	World Bank (2023)	492	17634.02	66931.4	90.00	447929.9
Nitrous oxide	Nit	Nitrous oxide emissions (thousand metric tons of CO2 equivalent)	World Bank (2023)	492	540.081	1026.9	30.00	6600.0
Ambient air pollution	Amb	Mean population exposure to PM2.5	OECD Statistics	492	18328.02	25412.2	10.00	135840.0

Note: N is the number of observations; S. Dev is the standard deviation; Min is the minimum; Max is the maximum.

3.2. Theoretical model

The theoretical foundation of our empirical analysis is ingrained in the extended stochastic impacts by regression on population, affluence, and technology (STIRPAT) model proposed by Dietz and Rosa (1994, 1997). This model is based on the idea that population size, affluence, and technology adoption have major effects on environmental quality. According to York et al. (2003), the STIRPAT model is widely used in empirical research because it allows one to (i) control for other factors affecting the environment and (ii) capture the elasticity of the impacts of population, affluence, and technology on environmental performance. We specify the STIRPAT model as follows:

$$I = (A, P, T) \tag{1}$$

where I is environmental quality ($Envt$), P is population size (Popt), A is affluence (G$dppc$), and T is technological progress (*Ictdif*). We modify the STIRPAT model in Equation 1 to include other factors that affect the environment to obtain Equation 2:

$$Envt = (EE, Gini, Gdppc, Popt, Ictdif, Lfpr, Trade, Dinvt) \tag{2}$$

From these theoretical specifications, we linearise Equation 2 as:

$$Envt_{it} = \lambda_0 + \rho_0 EE_{it} + \rho_1 Gini_{it} + \rho_2 Popt_{it} + \rho_3 Lfpr_{it} + \rho_4 Ictdif_{it} + \rho_5 Dinvt_{it} + \rho_6 Gdppc_{it} + \rho_7 Trade_{it} + \varepsilon_{it} \tag{3}$$

To analyse the moderating role of income inequality in the relationship between energy equity and environmental quality, we extend Equation (3) by introducing an interaction term for these variables, as seen in Equation (4):

$$Envt_{it} = \lambda_0 + \rho_0 EE_{it} + \rho_1 Gini_{it} + \rho_2 (EE \times Gini)_{it} + \rho_3 Popt_{it} + \rho_4 Lfpr_{it} + \rho_5 Ictdif_{it} + \rho_6 Dinvt_{it} + \rho_7 Gdppc_{it} + \rho_8 Trade_{it} + \varepsilon_{it} \tag{4}$$

where λ_0 is a constant term, *Lpfr* is employment; Trade is trade openness, and *Dinvt* is a domestic investment. Also, *EE* is a measure of energy equity (EE_2 and EE_2), Gini is income inequality and $(EE \times Gini)$ is the interaction between energy equity and income inequality. and $\boldsymbol{\varepsilon}$ is the error term.

The main parameters of interest in Equation (4) are ρ_0, ρ_1 and ρ_2, which capture the impact of energy equity, income inequality, and the conditional effects of energy equity on environmental quality, respectively. For the computation of the corresponding total effect, which answers Hypothesis 3, we differentiate Equation 4 with respect to energy equity to obtain:

$$\frac{\partial(Envt)}{\partial(EE)} = \rho_0 + [\rho_2(\overline{Gini})] \qquad (5)$$

where $\overline{Gini}$ is the average value of income inequality.

3.3 Estimation technique

We estimate the above Equation 4 by applying the Driscoll-Kraay (DK) standard error method Driscoll and Kraay (1998). The DK estimator is a non-parametric approach that assumes robust standard errors and corrects for autocorrelation and heteroscedasticity, which estimators such as pooled least squares ignore in panel analysis. Also, the DK model is applicable to both balanced and unbalanced panel analysis and can handle missing values. Additionally, the DK model provides a robust estimate that accounts for both temporal and cross-sectional dependence (Hoechle, 2007). To assess the validity of our estimates, we compare the values of the DK model to those of the two-step system generalised method of moments (SYS-GMM).

However, the DK regression does not control for endogeneity, which may arise since the independent variable may be related to the error term. For instance, endogeneity exists because of the inclusion of the lag of Envt. Hence, controlling for this possible endogeneity issue requires using the two-step system GMM estimator proposed by Kripfganz (2022), which is an extension of the Arellano and Bond (1991) approach. Previous studies have shown that the system-GMM estimator is appropriate when the number of countries (N) is greater than the study period (T), which is the case in this study (see., Ofori et al., 2024; Ofori et al., 2023).

Finally, we assess the appropriateness of our SYS-GMM estimates on several fronts. First, we assess whether we pass the overidentification restriction. Accordingly, we apply Hansen (1982) and the Sargan test of over-identification. The test requires that the attendant p-values be insignificant. Second, we check for any second-order serial correlations in the residuals. This means that the test for no autocorrelation in the residuals must be accepted. Third, we analyse whether the instruments used in the GMM are relevant for estimating energy equity and income inequality. In other words, they should be correlated with endogenous variables in the model. Further, we assess the overall fit of the models using the F test.

4. Empirical results and discussion

4.1 Summary statistics

The descriptive analysis in Table 1 reveals that EE_1 and EE_2 average 0.307 (30.7%) and 0.192 (19.2%), respectively. These values indicate low distributive and procedural justice in Africa. The data also reveal a mean income inequality value of 46.934. The mean of environmental quality is 0.016, indicating an overall negative ecological impact. Table A.2 presents the correlations between the variables.

Figure A.2 shows the trend of greenhouse gas emissions and air pollution in the sampled countries over the study period. Figure A.2 clearly indicates that, except for other greenhouse gases, carbon emission, methane emission, and air pollution have been increasing over the study period. Figure A.3 also portrays the level of energy equity – rural and urban access to electricity, and clean cooking fuel, and technology in Africa – in the sampled countries. The figure shows that energy equity is high in Mauritius and South Africa and markedly low in Togo, the Central African Republic, Mozambique, and the Democratic Republic of the Congo. Taking note of the environmental quality index, we present a distributional map for the years 2008, 2012, and 2019 to clearly show the spatial distribution of environmental quality. Figure 2 shows increasing levels of environmental degradation, especially in countries such as Nigeria, South Africa, and Ethiopia.

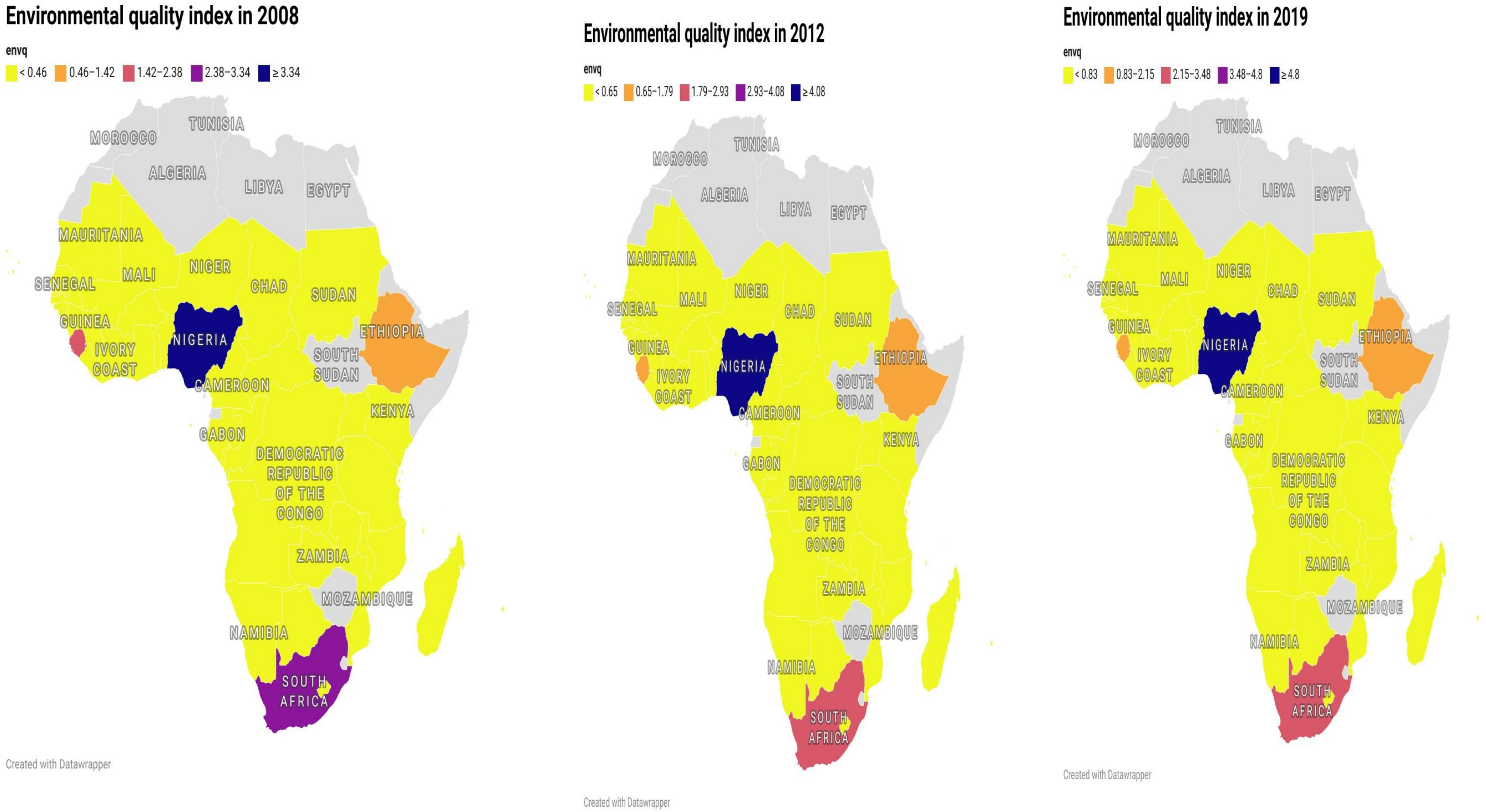

Figure 2: Environmental quality index in African countries, 2008-2019

4.2 Cross-sectional dependence test

The study tested for the presence/absence of cross-sectional dependence (CD) in the data. To do so, we applied the Pesaran (2015) CD test. The results in Table 2 show strong cross-sectional dependence for variables such as population, trade openness, ICT diffusion, GDP per capita, and energy equity 1.

Table 2: Cross-sectional dependence

Variables	CD-test	p-value
Environmental quality	51.248***	0.000
Population	60.463 ***	0.000
Employment	3.169**	0.002
Domestic investment	2.924**	0.003
Trade openness	4.944***	0.000
ICT diffusion	107.997***	0.000
GDP per capita	55.037***	0.000
Energy equity 1	30.868***	0.000
Energy equity 2	-1.076	0.282
The Gini index	-0.181	0.856

Note: Under the null hypothesis of cross-section independence, CD ~ N (0,1); *** p<0.01, ** p<0.05, * p<0.1

4.3 Results from the Driscoll and Kraay panel regression

The estimates in Tables 3-4 should be interpreted with caution. Specifically, a positive coefficient indicates a decrease in environmental quality, signifying a deterioration in environmental quality. A negative coefficient suggests otherwise.

Concerning Hypothesis 1, the evidence suggests that an increase in EE_1 promotes environmental quality (Column 2). We find that EE_1 reduces Envt by 0.5163%. From Column 4, we pay keen attention to Hypothesis 2, examining the unconditional effect of income inequality on Envt. The results show that an increase in the Gini index by one-point increases Envt by 0.0083 points at a 1% significance level. The evidence reveals that income inequality is positively related to Envt or air pollution and greenhouse gas emissions. This result validates Hypothesis 2.

That said, we now shift our focus to Hypothesis 2, discussing the contingency effects of income inequality on the EE-Envt relationship. Compelling shreds of evidence in Columns

7-8 show that the interaction term for energy equity (EE_1 & EE_2) and income inequality is positive, indicating that income inequality moderates energy equity to degrade the environment. From Columns 7-8, we report the total effect. The total effect of the role of EE_1 in moderating the effect of income inequality on Envt is -0.4325= ([46.9342× 0.153] + [-7.6292]). In the corresponding computation, 46.9342 is the mean value of income inequality, -7.606 is the direct effect of income inequality on Envt, and 0.153 is the interactive effect (indirect) of income inequality on Envt. Similarly, the total effect of the role of EE_2 in moderating the effect of income inequality on Envt is 0 .593 = ([46.934× 0.186] + [-8.117]). In other words, energy equity (EE_1 & EE_2) promotes environmental quality and income inequality counteracts the positive effect of energy equity on Envt in Africa (validation of hypothesis 2).

Table 3: Effects of energy equity and income inequality on Environmental Quality (DK Estimates)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	-0.5628	-0.1313	-0.6491*	-0.5037	-0.2285	-1.0245*	-0.7551	-1.3031*
	(0.5024)	(0.5191)	(0.3198)	(0.3590)	(0.5553)	(0.4893)	(0.5012)	(0.5941)
Employment	-0.6742***	-0.8914**	-0.6697***	-0.6869***	-0.8766**	-0.6855***	-0.3258	-0.5902***
	(0.1196)	(0.3620)	(0.1482)	(0.1189)	(0.3454)	(0.1431)	(0.3222)	(0.1065)
Investment	0.0008	-0.0014	0.0008	0.0012	-0.0011	0.0009	-0.0015	0.0009
	(0.0015)	(0.0010)	(0.0015)	(0.0014)	(0.0009)	(0.0015)	(0.0011)	(0.0014)
Trade	-0.0075***	-0.0084***	-0.0074***	-0.0077***	-0.0085***	-0.0076***	-0.0067***	-0.0052***
	(0.0003)	(0.0006)	(0.0003)	(0.0004)	(0.0006)	(0.0003)	(0.0008)	(0.0006)
ICT diffusion	0.0216***	0.0246**	0.0210*	0.0123**	0.0172**	0.0186	0.0039***	-0.0028
	(0.0067)	(0.0092)	(0.0098)	(0.0042)	(0.0059)	(0.0104)	(0.0009)	(0.0023)
GDP per capita	0.1646**	0.2283**	0.1656**	0.1746***	0.2434***	0.1417**	0.4589***	0.2645***
	(0.0610)	(0.0744)	(0.0666)	(0.0408)	(0.0467)	(0.0523)	(0.0239)	(0.0286)
EE_1		-0.5163*			-0.4680		-7.6292***	
		(0.3121)			(0.2952)		(0.5281)	
EE_2			0.0617			0.2366		-8.1170***
			(0.3968)			(0.4895)		(0.6801)
Gini				0.0083***	0.0064	0.0093*	-0.0702***	-0.0489***
				(0.0011)	(0.0037)	(0.0051)	(0.0084)	(0.0055)
EE_1 **× Gini**							0.1533***	
EE_2 **× Gini**							(0.0073)	
Constant								0.1856***
								(0.0084)
Total effect	–	–	–	–	–	–	0.4325**	0..5929**
	–	–	–	–	–	–	(0.2270)	(0.2915)
F-statistics	974.78***	1311.50***	794.37***	1097.22***	1225.45***	814.41***	8057.39***	86589.43***
R-squared	492	434	492	492	434	492	434	492
Observations	0.1053	0.1165	0.1054	0.1039	0.1154	0.1087	0.2267	0.2165
Countries	492	434	492	492	434	492	434	492

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

4.4 Results from the two-step system GMM regression.

For Hypothesis 1, our findings reveal an increase of 1% in the ratio of rural to urban access to electricity (EE_1) is associated with a decline in Envt by 0.021 points. Similarly, a 1% increase in the ratio of the rural population to the urban population with access to clean cooking fuel and technologies (EE_2) is linked to a reduction in Envt by 0.006 points. In other words, EE_1 and EE_2 enhance environmental quality in Africa.

The outcomes of our study, coupled with findings from other researchers, can be explained as follows: First, access to clean cooking fuel has been shown to mitigate air pollution and reduce carbon emissions. Moreover, achieving parity in clean cooking technologies facilitates the transition from traditional sources such as wood and charcoal to electric cookstoves, solar cookers, and other clean energy alternatives. These findings align with the principles of environmental justice, suggesting that equitable access to renewable energy and cooking technologies is instrumental in environmental preservation and the quality of life. In many African households, where traditional cooking methods are commonly practised (Vigolo et al., 2018), our evidence suggests that distributional energy justice is environmentally progressive. The evidence corroborates prior studies in Asian countries (Bilgili et al., 2022), China (Sun et al., 2022), the G11 countries (Mehmood, 2021), the OECD (Zafar et al., 2020) and Nordic countries (Khan et al., 2020). However, it contradicts that of Mehmood (2021) for South Asian countries, and Mahalik et al. (2021) for the BRICS.

We now turn our attention to Hypothesis 2. The findings in Column 3 indicate that income inequality degrades environmental quality. We show that a 1% increase in income inequality is associated with a 0.008point increase in Envt. This is plausible because, in countries with high income inequality, the masses may have limited access to essential environmental goods and services, such as clean fuel and technologies. Moreover, this empirical finding is consistent with Torras and Boyce (1998), who argues that heightened income inequality entrenches the power gap between poor and rich economies, which can impede environmental sustainability. This is because the elites and rich people may take advantage of the environment more due to their consumption and purchasing power, but the cost and consequences are usually borne by the poor.

Table 4: Effects of energy equity and income inequality on environmental quality (SYS-GMM Estimates)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Envt (-1)	0.9570***	0.9787***	0.9513***	0.9289***	0.9786***	0.9552***	0.9805***	0.9112***
	(0.0039)	(0.0039)	(0.0029)	(0.0015)	(0.0038)	(0.0025)	(0.0052)	(0.0240)
Population	0.0737	0.1713**	0.1391	-0.3964***	0.1646**	0.0539	0.2086	-0.3795
	(0.0962)	(0.0714)	(0.0932)	(0.1011)	(0.0731)	(0.0827)	(0.1497)	(0.2948)
Employment	0.0544*	0.0465	0.0583**	0.0063	0.0409	0.0473	0.0620	-0.0651
	(0.0323)	(0.0330)	(0.0237)	(0.0151)	(0.0321)	(0.0309)	(0.0528)	(0.0641)
Domestic investment	0.0003	-0.0005***	-0.0001***	-0.0001***	-0.0005***	0.0003	-0.0006***	0.0003
	(0.0003)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0002)	(0.0002)	(0.0002)
Trade openness	0.0000	0.0009***	0.0004***	0.0006***	0.0010***	-0.0000	0.0009***	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0002)	(0.0002)
ICT diffusion	-0.0012***	-0.0013***	-0.0015***	0.0001	-0.0014***	-0.0013***	-0.0011***	-0.0008
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0003)	(0.0008)
GDP per capita	0.1171***	0.0684***	0.1063***	0.0952***	0.0620***	0.1043***	-0.0038	0.1279***
	(0.0264)	(0.0120)	(0.0117)	(0.0074)	(0.0110)	(0.0205)	(0.0116)	(0.0463)
EE_1		-0.0210**			-0.0182**		-0.4254**	
		(0.0088)			(0.0084)		(0.1964)	
EE_2			-0.0056*			-0.0172*		-2.4714*
			(0.0031)			(0.0100)		(1.2855)
Gini				0.0069***	0.0010***	0.0007***	-0.0137***	-0.0467**
				(0.0003)	(0.0002)	(0.0003)	(0.0034)	(0.0213)
EE_1 x Gini							0.0100***	
							(0.0037)	
EE_2 x Gini								0.0602*
								(0.0314)
Constant	-1.4481***	-1.4513***	-1.6485***	0.4426	-1.3972***	-1.2600***	-0.4731	2.8928**
	(0.2510)	(0.2551)	(0.3582)	(0.3812)	(0.2633)	(0.3113)	(0.5819)	(1.4474)
Total effect	–	–	–	–	–	–	0.0457	0.3549*
	–	–	–	–	–	–	(0.0562)	(0.1950)
Sargan P-value	0.6252	0.6671	0.3227	0.3323	0.6024	0.8233	0.8887	0.9344
Hansen P-value	0.4830	0.2629	0.9830	0.1103	0.1638	0.7070	0.1391	0.0577
AR(1)	0.0528	0.0421	0.0516	0.0517	0.0424	0.0488	0.0382	0.0562
AR(2)	0.4313	0.4439	0.3772	0.4078	0.4458	0.4233	0.4435	0.6845
Instruments	19	31	31	40	32	32	29	30
Observations	491	433	491	491	433	491	433	491
Countries	41	41	41	41	41	41	41	41

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

Furthermore, in economies with significant income gaps, the poor tend to exploit natural resources to meet their basic needs. These findings align with findings drawn in African countries (Baloch et al., 2020), ASAEN-5 countries (Masud et al., 2018) and in high-income countries (Knight et al., 2017). The result is, however, parallel to Grunewald et al. (2017) for low and middle-income countries.

We now delve into Hypothesis 3, examining the interactive role of income inequality in the relationship between EE and Envt. The compelling evidence in Columns 7-8 demonstrates that income inequality interacts with all energy equity dynamics to hamper the environment. Precisely, we report total effects of 0.0457 and 0.355 for EE_1 and EE_2, respectively. The analysis reveals that income inequality nullifies the environmental quality-enhancing effect of energy equity, affirming Hypothesis 3. The moderating effect of income inequality on Envt can be explained as follows: Firstly, in societies characterised by high-income inequality, such as in Africa, there is limited access to environmental goods and services, leading to heavy reliance on traditional energy sources.

For the control variables, we concentrate on the estimates in Column 1. Except for population, the results reveal that employment, trade openness and domestic investment are statistically significant at 1%. The results show that an increase in ICT diffusion by 1% has a negative and significant effect on Envt, aligning with Avom et al. (2020). In contrast, GDP per capita impedes the Envt, as reported by Sarkodie and Strezov (2018).

The validity of our results is assessed through post-estimation tests. The insignificance of the AR (2) p-value suggests the absence of second-order serial correlation with the idiosyncratic error term. Furthermore, the non-significant p-value of the Sargan/Hansen test indicates that the instruments employed in the model are valid and reliable in addressing the endogeneity problem. Additionally, the number of instruments is less than the number of countries, providing clear evidence of the validity of our instruments. Finally, the findings are also robust and consistent with econometric issues such as cross-sectional dependence, endogeneity, and heteroscedasticity.

4.5 Robustness checks

In this section, we conduct robustness checks using the ecological footprint as an alternative outcome variable to validate the findings presented in Tables 3 and 4 using the DK and SYS-GMM strategies, respectively.

Table 6: Effects of energy equity and income inequality on the ecological footprint (DK Estimates)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.0219**	0.0046	0.0022	0.0204**	0.0021	-0.0061	-0.0044	-0.0080
	(0.0076)	(0.0037)	(0.0080)	(0.0073)	(0.0036)	(0.0071)	(0.0037)	(0.0053)
Employment	-0.0042	0.0003	-0.0035	-0.0045	0.0003	-0.0039	0.0048	-0.0032
	(0.0028)	(0.0032)	(0.0027)	(0.0028)	(0.0030)	(0.0028)	(0.0031)	(0.0027)
Domestic investment	0.0001	0.0002	-0.0001	0.0002	0.0002	-0.0001	-0.0001	-0.0002
	(0.0005)	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0006)	(0.0007)	(0.0006)
Trade openness	0.0020***	0.0028***	0.0024***	0.0019***	0.0026***	0.0023***	0.0037***	0.0034***
	(0.0006)	(0.0003)	(0.0006)	(0.0006)	(0.0003)	(0.0006)	(0.0003)	(0.0004)
ICT diffusion	0.0034	0.0031	0.0020	0.0034	0.0029	0.0015	-0.0042	-0.0052**
	(0.0055)	(0.0060)	(0.0044)	(0.0054)	(0.0058)	(0.0038)	(0.0035)	(0.0018)
GDP per capita	0.4536***	0.4889***	0.4515***	0.4335***	0.4607***	0.4120***	0.5809***	0.4621***
	(0.0390)	(0.0598)	(0.0410)	(0.0366)	(0.0599)	(0.0394)	(0.0453)	(0.0274)
EE_1		0.3251**			0.3426***		-3.5564***	
		(0.1188)			(0.1086)		(0.1497)	
EE_2			0.6679***			0.8552***		-3.2318***
			(0.0625)			(0.0550)		(0.4018)
Gini				0.0061***	0.0088***	0.0118***	-0.0331***	-0.0169***
				(0.0011)	(0.0011)	(0.0010)	(0.0011)	(0.0023)
EE_1 x Gini							0.0838***	
							(0.0033)	
EE_2 x Gini								0.0894***
								(0.0074)
Constant	-3.2758***	-3.0624***	-2.3734***	-3.2935***	-3.1081***	-2.1546**	-2.1280***	-1.2071***
	(0.7236)	(0.7384)	(0.7579)	(0.7199)	(0.7287)	(0.7189)	(0.5551)	(0.3882)
Total effect	–	–	–	–	–	–	0.3752***	0.9660***
	–	–	–	–	–	–	(0.1152)	(0.060)
Observations	492	434	492	492	434	492	434	492
R-squared	0.5345	0.5469	0.5538	0.5383	0.5553	0.5667	0.6371	0.6252
Countries	42	42	42	42	42	42	42	42

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

Table 7: Results of the effect of energy equity and income inequality on the ecological Footprint (SYS-GMM Estimates)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ecological footprint (-1)	-0.8210***	0.2462***	-0.8847***	-0.7979***	0.2179***	-0.8829***	0.2521***	-0.6416***
	(0.0305)	(0.0185)	(0.0411)	(0.0508)	(0.0234)	(0.0415)	(0.0488)	(0.0893)
Population	-0.0203**	-0.0992***	-0.0254**	0.0405***	-0.0707***	-0.0245**	-0.0025	0.0211
	(0.0083)	(0.0147)	(0.0110)	(0.0152)	(0.0198)	(0.0109)	(0.0122)	(0.0214)
Employment	-0.0300***	-0.0242***	-0.0272***	0.0146***	-0.0208***	-0.0280***	0.0092***	0.0059
	(0.0043)	(0.0025)	(0.0051)	(0.0034)	(0.0029)	(0.0052)	(0.0025)	(0.0049)
Domestic investment	-0.0002	0.0004	0.0001	-0.0003***	-0.0001	0.0001	0.0018*	0.0005
	(0.0002)	(0.0003)	(0.0003)	(0.0001)	(0.0004)	(0.0003)	(0.0010)	(0.0008)
Trade openness	0.0027***	0.0019***	0.0014*	-0.0001	0.0019***	0.0015	-0.0014	0.0000
	(0.0005)	(0.0004)	(0.0007)	(0.0004)	(0.0004)	(0.0010)	(0.0011)	(0.0005)
ICT diffusion	-0.0231***	-0.0051***	-0.0247***	-0.0284***	-0.0058***	-0.0246***	-0.0085***	-0.0200***
	(0.0015)	(0.0007)	(0.0018)	(0.0017)	(0.0006)	(0.0018)	(0.0011)	(0.0024)
GDP per capita	1.5492***	0.9577***	1.5053***	1.1756***	0.7332***	1.4979***	0.2251**	0.6618***
	(0.0782)	(0.0680)	(0.0807)	(0.0612)	(0.1333)	(0.0820)	(0.1113)	(0.1233)
EE_1		0.1308*			0.0783		-5.0933***	
		(0.0679)			(0.0902)		(1.2783)	
EE_2			0.0906			0.0628		-2.1658
			(0.3130)			(0.3190)		(3.1600)
Gini				0.0026*	0.0227***	0.0021	-0.0139	0.0230
				(0.0015)	(0.0086)	(0.0145)	(0.0163)	(0.0214)
EE_1 x Gini							0.1153***	
							(0.0254)	
EE_2 x Gini								0.0667
								(0.0738)
Constant	-6.6698***	0.4453	-6.0561***	-9.9756***	-0.5262	-6.0896***	-0.5816	-5.6928***
	(0.8532)	(0.7273)	(0.8894)	(0.9827)	(0.7079)	(0.9950)	(0.7280)	(1.6868)
Total effect	–	–	–	–	–	–	0.3163**	0.9635**
	–	–	–	–	–	–	(0.1598)	(0.4582)
Sargan P-value	0.2084	0.4031	0.2582	0.2411	0.3792	0.0392	0.3966	0.2230
Hansen P-value	0.9830	0.1265	0.2642	0.2144	0.3576	0.1410	0.1230	0.1640
AR (1)	0.0649	0.0140	0.2316	0.0925	0.0193	0.0392	0.0223	0.0475
AR (2)	0.2194	0.4601	0.0286	0.3663	0.2886	0.4405	0.3299	0.1078
Instruments	37	37	28	30	30	28	29	27
Observations	491	433	491	491	491	433	433	491
Number of countries	41	41	41	41	41	41	41	41

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

We evaluate the effects of energy equity, income inequality, and their interaction terms on the ecological footprint. For Hypothesis 1, EE_1 has a positive effect on the ecological footprint at the 1% significance level (see column 2 of Tables 6 and 7). For instance, increasing EE_1 by 1% increases the ecological footprint by 0.325 (DK) or 0.286 (SYS-GMM). In Column 3 of both Tables, EE_2 It also has a positive effect on ecological footprint, albeit not statistically significant for the GMM estimates in Table 7. This can be attributed to Africa's unequal access to energy, which has resulted to higher ecological footprint. We also find that income inequality increases the ecological footprint for both DK (0.0061) and GMM (0.0026) at a 10% significance level.

Further, we also find empirical evidence for Hypothesis 2 as well. First, income inequality moderates EE_1 to increase the ecological footprint by 0.0838 and 0.316 for the DK model and GMM estimates, respectively (see column 7). Second, the interaction terms for income inequality and EE_2 yield a joint effect of 0.0895 and 1.896 in terms of DK and GMM, respectively. The results indicate that income inequality mitigates the positive effect of energy equity on the ecological footprint in Africa. As we found in the case of Envt in Africa, income inequality, both directly and indirectly, counteracts the positive effect of energy equity on the ecological footprint in Africa. However, we find that income inequality mitigates the positive effect of energy equity on ecological footprint. In sum, we find that the findings obtained in the DK model are consistent with the GMM. Lastly, the findings obtained in Tables 6 and 7 using the ecological footprint as an outcome variable are consistent with the results in Tables 3 and 4, which validate the reliability and validity of the study's results.

5.0 Conclusion and policy implications

This study contributes to the environmental sustainability literature by assessing the unconditional and conditional effects of energy equity on environmental quality in Africa. This study differs from past research by investigating the influence of income inequality in the relationship between energy equity and environmental quality. The empirical analysis is based on macro data for 41 African countries from 2008-2019. We apply the Driscoll-Kraay pooled least squares and the dynamic system GMM estimators. Lastly, the authors conducted robustness checks to validate the results using ecological footprint.

The following empirical findings are drawn from the study. First, we find strong evidence that energy equity, measured by rural-urban equality in electricity access and clean cooking fuel and technologies, directly increases environmental quality. Second, the results demonstrate that income inequality hampers environmental quality. Third, the interactive analysis reveals that income inequality negates the positive effect of energy equity on environmental quality. The main message from this empirical enquiry is that although energy equity promotes environmental sustainability, income inequality nullifies the positive effect.

Our research findings have significant policy implications for African countries. First, our empirical results underscore the importance of energy equity as a key factor contributing to environmental quality. Accordingly, we recommend that African governments should deepen efforts to ensure equitable access to renewable energy and clean cooking fuel and technologies to foster environmental quality. We suggest that NGOs and development partners, such as the Norwegian Sovereign Wealth Fund and the Bill and Melinda Gates Foundation, actively support these initiatives by providing green funding. Furthermore, governments should prioritise investments in clean energy production, green technologies, and distribution to reduce environmental pollution by providing benefits like tax relief reforms, financial incentives, flexible barriers and environmental taxes like carbon pricing. Additionally, African governments should implement initiatives, including awareness campaigns such as clean cooking initiatives and energy-saving technologies to clean energy sensitise the public on the health and environmental quality impacts of (un)clean energy consumption.

Second, the empirical evidence suggests that income inequality is detrimental to environmental quality. This emphasises the significance of implementing distributive policies that ensure an even distribution of wealth in an economy to mitigate environmental pollution. Such policies may involve targeted educational programs, job creation initiatives, and progressive taxation policies aimed at fostering equitable resource distribution and access to opportunities. This can be complemented by governments broadening social transfers to poor/vulnerable households. Third, consistent with the interactive analysis, we recommend that comprehensive reforms that target fairer income inequality should be implemented. By doing so, energy equity improvements might lead to a win-win situation, as suggested by the distributional hypothesis.

To expand the scope of this study, future research could explore whether the interaction effect between energy equity and income inequality has distinct effects in low-income, middle-income, and high-income countries.

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Appendices

Table A1: List of countries

Angola
Benin
Botswana
Burkina Faso
Burundi
Cabo Verde
Cameroon
Central African Republic
Chad
Comoros
Congo, Democratic Republic
Congo, Republic
Cote d’Ivoire
Ethiopia
Gabon
The Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mozambique
Namibia
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
South Africa
Sudan
Sao Tome and Principe
Tanzania
Togo
Uganda
Zambia

Table A2: Correlation matrix, 2008-2019

	Envt	EF	popt	lfpr	dinvt	trade	iCTdif	gdppc	EE$_1$	EE$_2$	gini	hfcpfcsf6	pm25	co2	n2o	ch4
Envt	1.0000															
EF	0.0486	1.0000														
Popt	0.0744	0.6130***	1.0000													
Lfpr	-0.1700***	-0.3170***	-0.2910***	1.0000												
Dinvt	-0.0474	-0.0623	-0.0790	0.0708	1.0000											
Trade	-0.1820***	0.3360***	0.4230***	-0.0778	0.0542	1.0000										
Ictdif	0.1650***	0.3680***	0.5380***	-0.1530***	-0.1070*	0.1010*	1.0000									
Gdppc	0.0881*	0.7720***	0.7750***	-0.3350***	-0.0688	0.3510***	0.5200***	1.0000								
EE$_1$	0.1490***	0.5140***	0.7390***	-0.4610***	-0.1060*	0.0595	0.5220***	0.5770***	1.0000							
EE$_2$	0.1100*	0.5510***	0.7120***	-0.2910***	-0.0760	0.2090***	0.4440***	0.6750***	0.5810***	1.0000						
Gini	0.0808	0.4030***	0.4060***	-0.1630***	-0.0295	0.2550***	0.2230***	0.3500***	0.2680***	0.0897*	1.0000					
PCA	**Variables**															
Ghgs	0.5930***	0.2730***	0.2080***	-0.1630***	-0.0227	-0.0578	0.2170***	0.2230***	0.2680***	0.2390***	0.2730***	1.0000				
Pm25	0.1860***	-0.2010***	-0.2900***	-0.0176	-0.0120	-0.1460***	-0.0871*	-0.2000***	-0.1610***	-0.1620***	-0.2090***	0.0279	1.0000			
Co2	0.5730***	0.4900***	0.3650***	-0.1870***	-0.0364	-0.0509	0.4060***	0.3330***	0.4130***	0.3650***	0.4720***	0.6810***	-0.0364	1.0000		
N2o	1.0000***	0.0486	0.0744	-0.1700***	-0.0474	-0.1820***	0.1650***	0.0881*	0.1490***	0.1100*	0.0808	0.5930***	0.1860***	0.5730***	1.0000	
Ch4	0.8440***	0.0162	-0.0332	-0.0440	-0.0180	-0.2060***	0.1280**	0.0488	0.0838	0.0662	-0.0009	0.5610***	0.3660***	0.5490***	0.8440***	1.0000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.3: Retained factors used for construction of PCA.

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	2.9048	1.7805	0.5810	0.5810
Factor2	1.1243	0.6119	0.2249	0.8058
Factor3	0.5124	0.2140	0.1025	0.9083
Factor4	0.2984	0.1381	0.0597	0.9680
Factor5	0.1602	.	0.0320	1.0000

LR test: independent vs. saturated: chi2(10) = 1236.42 Prob>chi2 = 0.0000

Table A.4: Factor loadings (pattern matrix) and unique variances

Variable	Factor1	Factor2	Uniqueness	KMO
hfcpfcsf6	0.8158	-0.2838	0.2540	0.7848
pm25	0.2262	0.9193	0.1038	0.3631
co2	0.8044	-0.3452	0.2338	0.7635
n2o	0.8731	0.0687	0.2331	0.7071
ch4	0.8826	0.2734	0.1463	0.6562
Overall				0.6993

NB: Kaiser-Meyer-Olkin measure of sampling adequacy where the overall signifies mediocre

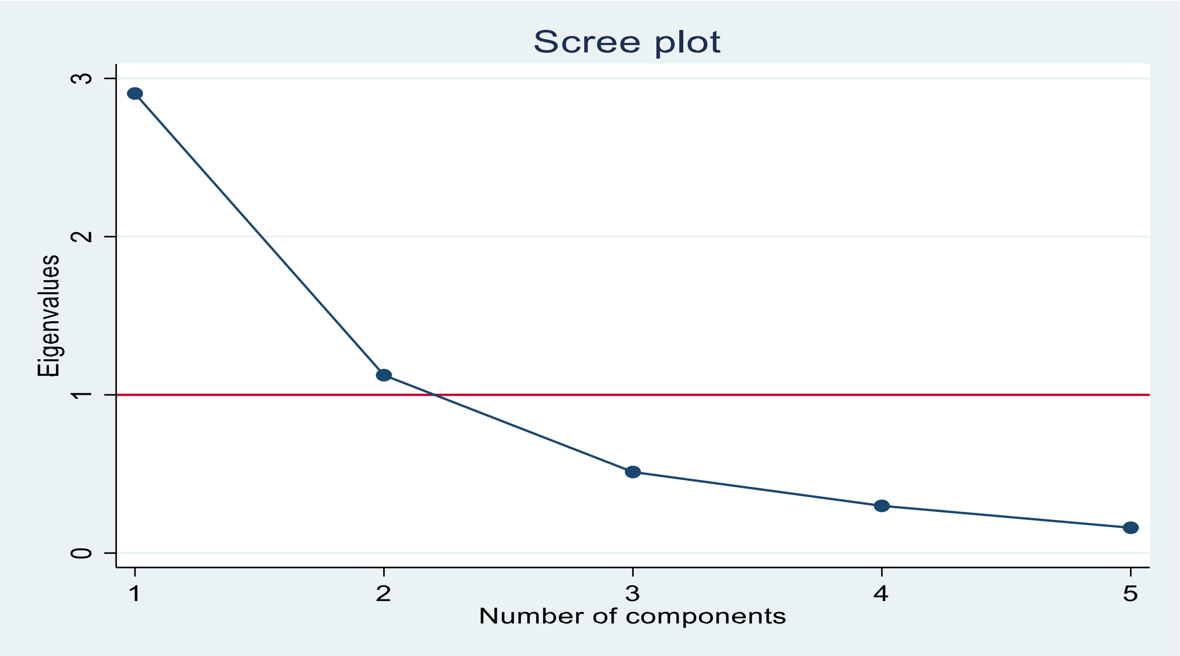
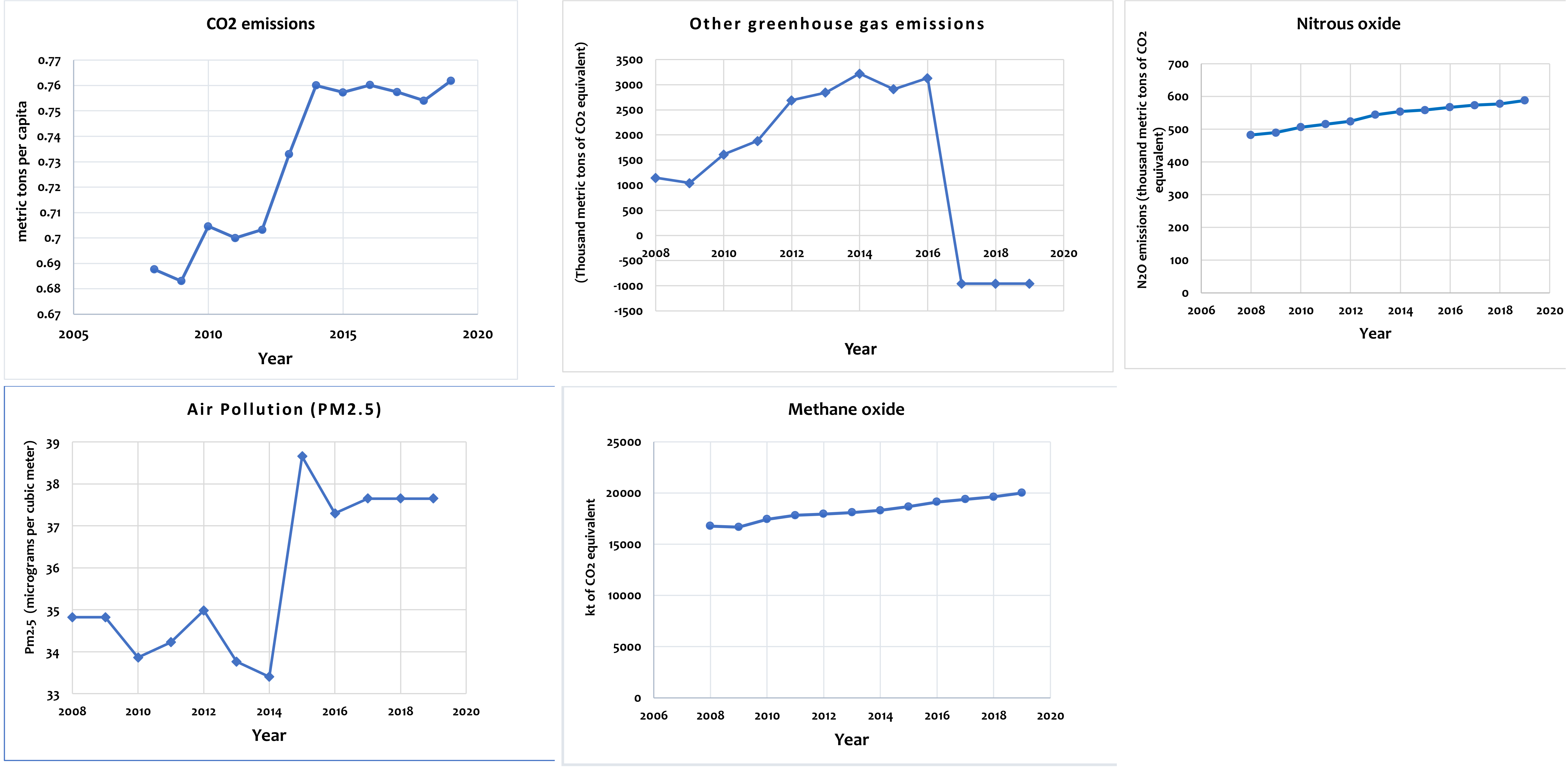


Figure A.1: Scree plot of environmental quality index



CO2 emissions

Other greenhouse gas emissions

Nitrous oxide

Air Pollution (PM2.5)

Methane oxide

Figure A.2: Trends of environmental quality indicators, 2008-2019

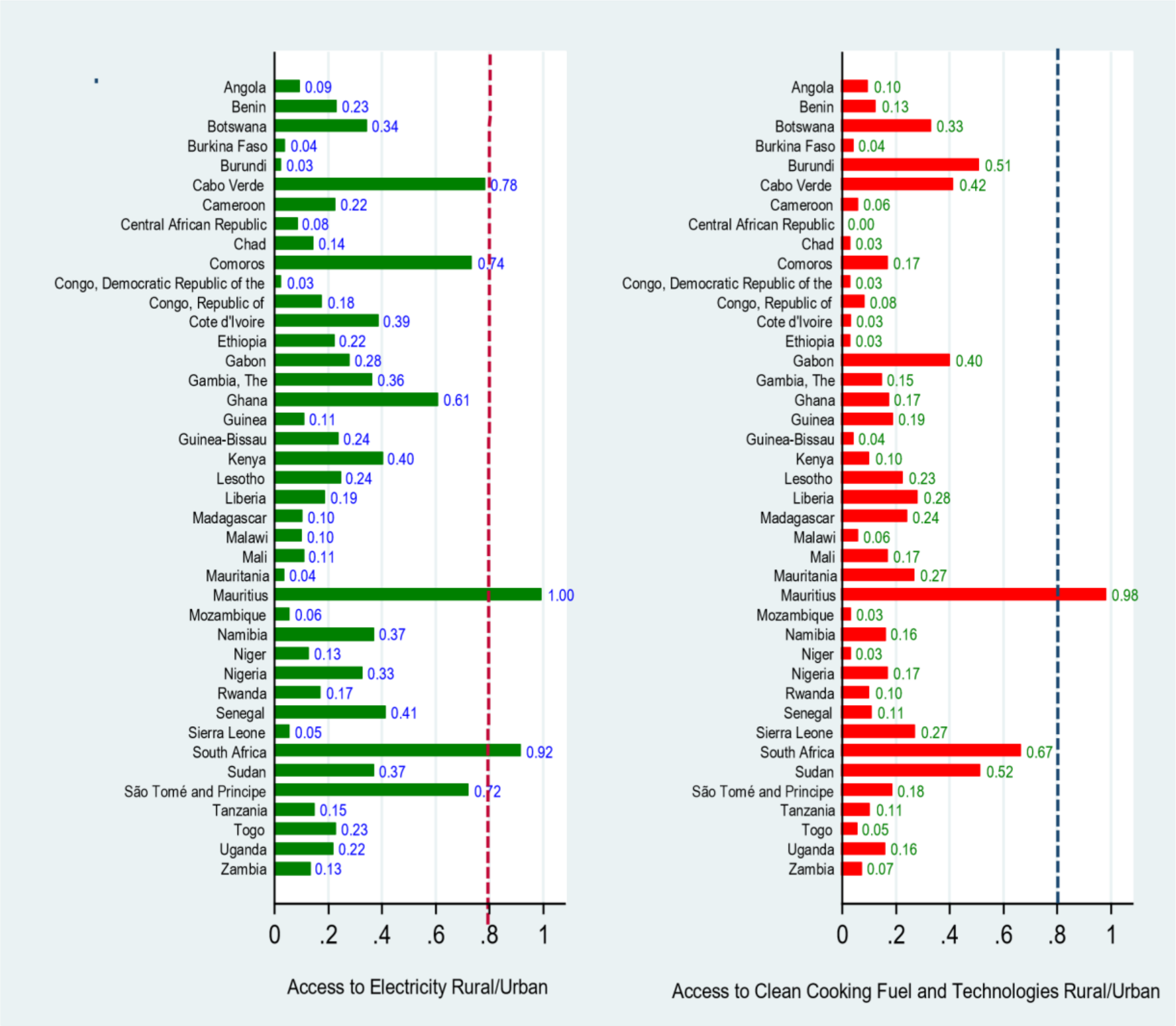


Figure A.3: In-country average of energy equity indicators, 2008-2019