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Impact of rural-urban energy equality on environmental sustainability and the role of governance

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Abstract

Globally, rural areas suffer from less infrastructure relative to urban areas. Political and development economists have mainly attributed this disparity in infrastructure distribution to governance. The literature has sufficiently discussed the role that rural-urban infrastructure inequality plays in development outcomes such as poverty. However, not much is known about the effect of the rural-urban infrastructure gap on the environment. To contribute to knowledge and policy discussions, we investigate the impact of rural-urban energy access (in)equality on environmental degradation and the role governance plays using data from 47 sub-Saharan African countries from 2000–2020. Evidence from the heteroskedasticity-based instrumental variable regression consistent with Driscoll and Kraay's estimation revealed that bridging rural-urban energy access inequality is associated with reduction in environmental degradation. We also documented that the direct effect of the governance-related variables used is mixed. The moderation and marginal effect estimates showed that improving governance quality conditions equality in rural-urban energy access to reduce environmental degradation. From a policy perspective, these findings suggest that the implementation of rural electrification policies supported by a good governance system would play a crucial role in mitigating environmental degradation in developing countries.

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1. Introduction

This study aims to contribute to policy discussions on pathways for addressing the rising environmental degradation from the perspective of rural-urban energy equality and the role that quality of governance plays. The influential paper of Grossman and Krueger (1995) highlighted that there is an inverse U-shaped relationship between economic growth and the environment, known as the Environmental Kuznets Curve (ECK) hypothesis. The policy implication of this inverse U-shaped relationship is that instead of economic growth being a threat to the environment, it would eventually enhance environmental sustainability (Stern, 2004). The practical justification is that the advanced stage of economic growth is associated with technological advancement, better environmental regulation, and the upgrade of industrial structures. The validity of the EKC hypothesis indicates that policymakers could substantially implement structural policies to advance economic growth for the betterment of the environment. Despite the policy implications of the EKC hypothesis, some studies have refuted the claims of the ECK hypothesis on theoretical and empirical grounds. Thus, some empirical studies find no evidence to support the EKC hypothesis (Farhani & Ozturk, 2015; Pal & Mitra, 2017; Stern & Common, 2001). At the same time, Stern and Common (2001) further argue that the EKC model is inadequate, and its estimates can suffer from omitted variable bias. These criticisms also indicate that it would be insufficient and ineffective for policymakers to base their actions on EKC's assumption to curb environmental degradation.

Based on the criticisms against the EKC hypothesis and its related empirical studies, we suggest that policymakers should look beyond economic growth as the only sustainable pathway for abating environmental degradation. We argue in this study that rural-urban energy equality is one of the important pathways for addressing environmental degradation. Rural households are known to depend extensively on environmental resources. To support their livelihoods, rural residents depend on rural land for farming and also extract resources such as timber, firewood, fish and non-timber products from the environment (Babulo et al., 2009; Nguyen, Do, Bühler, Hartje, & Grote, 2015). The uneven distribution of infrastructure and economic resources between rural and urban areas partly explains the overdependency of rural households on environmental resources. Urban areas are the hubs of administrative offices, financial institutions, industries, and formal jobs, among others. This makes urban areas well-fitted with infrastructure such as roads, electricity, etc., relative to rural areas. For instance, the lack of or poor infrastructure, such as electricity and clean cooking technologies and fuels in rural areas, has led the rural population to depend on the forest for energy (firewood and charcoal) and also generate income from the forest. In support of this argument, Babulo et al. (2009) showed that environmental income, especially forest income, occupies the second largest share of the average rural household income in Tigray, Northern Ethiopia. The extensive extraction of resources such as forests by rural populations contributes significantly to environmental degradation (Beck & Nesmith, 2001). Recently, there has been a suggestion that the improvement of rural-urban equality in access to electricity and clean cooking technologies and fuels has an environmental gain, especially a reduction in deforestation (Acheampong &

Opoku, 2023). However, not much is known empirically about the impact of rural-urban energy equality on environmental degradation to inform public policy. This research gap serves as one of the motivations for this study.

An important factor that cannot be overlooked when examining the impact of rural-urban energy equality on environmental degradation is the quality of governance. This is because, from an institutional economics perspective, the success of policies hinges on the quality of a country's governance (Acemoglu, Johnson, Robinson, & Thaicharoen, 2003). Weak governance will render issues of environmental degradation normal, and mitigating measures and efforts put in place might be immaterial (Enrici & Hubacek, 2016). Kammerlander and Schulze (2021) indicate that environmental regulation is not merely a response to environmental problems but the consequence of a political process in which the quality of governance becomes important. As Buizer, Humphreys, and de Jong (2014) note, governance shapes behaviour and practices to tackle common challenges, and it is imperative in environmental management and politics. In addition, the literature suggests that electricity is a capital-intensive infrastructure and also poses the feature of a natural monopoly (Onyeji, 2010), therefore making government involvement in investing in electricity infrastructure important (Best & Burke, 2017). The policy implication is that governance plays a significant role in the distribution of energy infrastructure between rural and urban areas (Acheampong, Nghiem, Dzator, & Rajaguru, 2023; Acheampong, Shahbaz, Dzator, & Jiao, 2022). Therefore, a better governance system that prioritizes rural economic development would support rural electrification projects and programs to enhance rural residents' access to modern energy (electricity and clean cooking technologies and fuels) (Acheampong et al., 2023). In other words, a weak governance system could render rural electrification policies ineffective, thereby limiting the rural population's access to modern energy. This discussion shows that bridging the rural-urban energy inequality gap is considered to thrive within the main governance/political architecture of countries (Opoku & Acheampong, 2023). Therefore, understanding the role that governance plays in the relationship between rural-urban energy equality and the environment is important to advance knowledge and inform policy. However, no evidence exists in the literature on the role that governance plays in rural-urban energy equality and environmental degradation relations.

Inspired by the discussions above and the research gaps, this study seeks to examine the effect of rural-urban energy equality on environmental degradation and the role that quality of governance plays using data from 47 sub-Saharan African (SSA) countries over the period 2000 to 2020. The SSA region is considered an important milieu for this study as it is the most energy-poor and the region with the greatest energy accessibility inequality in the world (FAO, 2022; IEA, IRENA, UNSD, WorldBank, & WHO, 2022). In addition, the Food and Agricultural Organization (FAO) estimates that about 2.6 billion people in the world rely on firewood and other biomass sources to meet household energy needs (FAO, 2022). The regional breakdown of this number highlights a disparate energy access situation in Africa. For example, about 63% of the African population is estimated to use firewood, 38% in Asia and Oceania, and 15% in Latin America and the Caribbean (FAO, 2022). It is, therefore, not surprising that the SSA region has the least access to modern and sustainable energy in the world. The downside of the use of unsustainable energy is its effect on emissions and deforestation, which are contributing greatly to climate change (Buizer et al., 2014). This study is policy relevant as it relates to at least three of the major Sustainable Development Goals (SDGs): Goals 7, 13 and 15. As energy issues align with Goal 7 - ensuring access to affordable, reliable, sustainable and modern energy for all, Goals 13 and 15 pertain to the protection of the environment. Goal 13 is about taking urgent action against climate change and its effects, and Goal 15 concerns life on earth, and it specifically seeks to “protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss”. Therefore, the findings from this study will contribute to the discourse on sustainable development and policy.

Apart from the policy relevance, this study contributes to the existing literature in the following ways. Firstly, it shifts away from the commonly used (fossil) energy consumption variable and applies a variable capturing inequality in access to energy between the urban and rural. This is the first empirical study to consider this in relation to environmental degradation. Following Trotter (2016) and Opoku and Acheampong (2023), the energy access inequality is operationalized as rural-urban equality in access to electricity and clean fuels and technologies for cooking. Rural-urban equality to access to modern and sustainable energy is posited as a reasonable measure for access to electricity by all due to the huge disparate access to modern and sustainable energy in rural areas. Approximately 80% of the rural population worldwide is estimated to lack access to electricity (IEA et al., 2022). It is also estimated that nearly 93% of the rural population lacks access to clean cooking fuels and technologies (IEA et al., 2022). Hence, a ratio of rural-urban equality close to unity depicts enhanced access to a large section of the population.

Secondly, this study examines how the governance infrastructure moderates the effect of the rural-urban energy gap on the environment. Even though some existing studies have examined the impact of institutional quality and its moderating effect on energy consumption in mitigating environmental degradation (Acheampong, Dzator, & Savage, 2021b; Adams & Acheampong, 2019), no study has yet focused on rural-urban energy gap that exhumes accessibility to modern and sustainable energy.

The remainder of the paper is as follows: Section two presents succinct literature (theoretical and empirical) on the topic, and section three presents the methodology and data of the paper. Section four presents and discusses the empirical results, and section five concludes the paper.

2. Determinants of environmental degradation

It is both theoretically and empirically upheld that largely energy consumption, especially fossil fuels, translates to harmful environmental consequences. The effect of energy consumption emanates from the use of energy in economic activities (including trade and investment activities) to boost economic growth. In line with this, the theoretical literature mainly points out two main factors (which depend on energy usage) that could have environmental effects: economic activities/economic growth and trade/foreign direct investment. The economic growth aspect through the famous EKC hypothesis posits that economic activities and, for that matter, economic growth affect the environment. Specifically, the EKC hypothesis suggests that, at the initial stages of growth, where the exploitation of resources and energy use are intense, environmental degradation is high; however, after a certain economic growth threshold, environmental quality starts to set in (Grossman & Krueger, 1991; Maddison, 2006). Regarding the trade/foreign direct investment aspect, the pollution haven hypothesis and pollution halo hypothesis postulate a relationship between investment and environmental degradation (Marques & Caetano, 2022). As the pollution haven hypothesis posits that an increase in foreign direct investment could lead to deterioration of the environment, particularly in developing countries, the pollution halo hypothesis argues that foreign direct investment could enhance environmental quality due to the superior technologies (such as energy efficiency and renewable energy usage) foreign firms possess relative to domestic firms (Cole, 2004; Copeland, 2008; Javorcik & Wei, 2003; Opoku, Acheampong, Dzator, & Kufuor, 2022).

Grossman and Krueger (1991) identify three separate mechanisms through which trade/economic activities can translate to increased environmental degradation (pollution). The first mechanism is the scale effect. The scale effect captures the notion that if trade and investment lead to an increase in economic activity, and if the nature of that activity remains the same, then the total amount of pollution generated from producing that activity must increase. The expansion in economic activity comes with increased demand for energy, and if this energy is not generated from sustainable sources, there will be increased environmental pollution with the increase in economic output. Grossman and Krueger (1991) further add that increased trade, for example, necessitates cross-border transportation services, and without changes in transportation practices, expanded trade would contribute to worsening air quality. The second mechanism is the composition effect, and this could result from changes in trade policy. With liberalized trade, countries are more likely to specialize in goods they have competitive advantage. Grossman and Krueger (1991) argue that if the competitive advantage of a country is mainly a result of differences in environmental regulations, then the composition effect of trade openness would be harmful to the environment. In this case, countries may be inclined to specialize in activities/areas that their governments do not have stringent environmental regulations on. In so doing, they evade the pollution abatement cost. Nevertheless, suppose the bases of competitive advantage are derived from factors such as technological differences and factor abundance. In that case, the effect on the environment can be complex and would depend largely on whether pollution-intensive activities grow or reduce in the country that, on average, has the strictest environmental regulations.

The last mechanism, which is the technique effect, captures the intuition that pollution per unit of economic activity need not be the same as prior to the liberalization of trade and investment. Two reasons could be put out for this; firstly, with liberalized trade and investment, in particular developing countries, foreign investors can transfer greener and cleaner technologies of production (mainly regarding energy use) that would increase output but at the same time reduce environmental degradation. This is in line with the halo effect hypothesis that claims that multinational enterprises contribute largely to host countries' sustainable environment (reduction in emissions) because they possess superior technologies friendly to the environment, i.e. green technologies (Adom, Opoku, & Yan, 2019). Secondly, if trade and investment liberation contribute to increased economic output, this would lead to increased income levels. Naturally, with increased income levels, the demand for cleaner environments will increase, and this would force governments to either enforce existing environmental regulations or enact stricter ones.

Research on the EKC, pollution haven, and halo effect hypotheses began Grossman and Krueger (1991), who examined the relationship between air quality (sulphur dioxide, particulates and smoke) and economic growth in 42 countries. They found that for sulphur dioxide and smoke, concentrations rise with per capita GDP (at low levels of national income) but fall with GDP growth at higher levels of income. Their finding births the EKC hypothesis. Following this, a number of empirical studies have followed with mixed conclusions. For example, Apergis and Ozturk (2015b) confirmed the hypothesis for 14 Asian countries over the period 1990–2011, and Cole (2003) also found evidence for 32 developed countries over the period 1975–1995. However, Azomahou, Laisney, and Van (2006) found no support using data from 1960–1996 on a panel of 100 countries. Roca, Padilla, Farré, and Galletto (2001) using data from Spain over the period 1973–1996, similarly, they did not find support (except in the case of one pollutant). In a sample of 20 OECD countries over the period 1870 to 2014, Awaworyi, Inekwe, Ivanovski, and Smyth (2018) only found evidence in 9 of the countries. Regarding trade openness, Cole (2004) found evidence for the pollution haven hypothesis 1980–1997 for a sample of OECD countries. He (2006) also found evidence using data over the period 1994–2001 from 29 provinces in China. Others such as Eskeland and Harrison (2003), Javorcik and Wei (2003) and Levinson (2020) either found no or very weak evidence for the pollution haven hypothesis in the United States and the Eastern European countries, respectively. Obviously, the support or otherwise of these hypotheses is subject to a number of factors, including sample (years and countries), methodology, and environmental degradation indicators used.

Analyses of the EKC/pollution haven (halo) hypotheses can be posited as indirect ways of examining the effect of energy consumption on the environment through the effect of energy on economic growth and trade/investment activities. Despite this, many studies have analysed the direct effect of energy consumption on environmental degradation. For example, Charfeddine (2017) finds that electricity consumption is positively related to an increase in ecological footprint and negatively related to carbon emissions for Qatar over the period 1970–2015. Abbas, Kousar, and Pervaiz (2021) find that, in the long run, energy consumption has a positive effect on carbon emissions for Pakistan over the period 1970–2018. Considering 17 OECD countries over the period 1977–2010, Bilgili, Koçak, and Bulut (2016) find a negative causality from renewable energy to carbon emissions. Wu, Xu, Ren, Hao, and Yan (2020), in using data from China (over the period 2006–2015) find that increasing energy consumption increases carbon emissions. Using a panel of 106 countries over the period 1971–2011, Antonakakis, Chatziantoniou, and Filis (2017) found heterogeneous effects of various types of energy consumption on emissions for different country groups. In India, over the period from 1971 to 2014, Ahmad et al. (2016) found that energy consumption (total energy, gas, oil, electricity and coal) increased carbon emissions. Using similar energy types, Saboori and Sulaiman (2013) found similar results for Malaysia over the period 1980–2009. For Saudi Arabia (using data over the period 1980–2011), Alkhathlan and Javid (2013) found that though oil and electricity consumption has a positive effect on carbon emissions, gas consumption is related to a reduction in emissions. Using data from 102 countries over the period 1996–2012, Le, Chang, and Park (2020) find that the use of non-renewable energy consumption is related to a rise in the level of emissions across varied income groups of countries.

In much of the existing literature interest in energy issues have focused on total consumption and mainly fossil energy (Jafari, Othman, & Nor, 2012). However, with the championing of the sustainable energy for all agenda and the SDGs (particularly Goal 7, 13 and 15), attention is shifting to the use of modern and sustainable energy. More importantly, the accessibility of energy by all has become very crucial. This aligns with the notion that energy is an important resource for survival in the 21st century, and ensuring that all people (whether in the rural or urban areas) have access to energy should be a matter of urgent policy concern. Considering the high infrastructural disparity in rural areas relative to the urban especially in many African countries, access to modern energy is luxury to many rural folks rendering some to rely on forest resources in meeting some energy demands at home. Access to modern and sustainable energy by all would reduce reliance on fossil fuels and forest resources, reduce emissions and deforestation, and generally environmental degradation.

Though the environmental economics literature is inundated with a plethora of studies examining factors that influence environmental degradation as stipulated above, none so far has considered the concept of the rural-urban energy access divide in any form or shape. This study, therefore, seeks to fill this gap and contribute to the general discussion on access to energy inequality focusing on the divide between the urban and rural. The present study also further analyses how governance moderates the effect of the rural-urban energy gap on the environment. The impact of government on energy affordability (prices) and energy infrastructure makes governance a crucial factor in the supply, distribution, and access to energy (Aluko, Opoku, Ibrahim, & Kufuor, 2023). Besides, the government's commitment is required to drive countries towards universal access and sustainable energy. Aluko et al. (2023), and Garrone, Piscitello, and D'Amelio (2019) highlight the role of governance in enhancing access to electricity. Governance and the general institutional framework are also considered important to the issue of sustainability (Danish, Baloch, & Wang, 2019; Dutt, 2008; Halkos & Tzeremes, 2013). Though the moderation effect of governance on the rural-urban energy gap is elusive, the literature abounds with the direct effect of governance on the environment. For instance, a sample of 124 countries over the period 1984–2002, Dutt (2008) finds that better quality of governance is associated with lower emissions. Danish et al. (2019) find similar results for BRICS countries from 1996 to 2017. However, using data from G20 countries over the period 1996–2010 Halkos and Tzeremes (2013) found results indicating that improving governance (measured with voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law and control of corruption) does not always relate to reduction in carbon emissions. Using data from 25 SSA countries over the period 1996–2010, Abid (2016) finds that though political stability, government effectiveness, democracy, and control of corruption exert a negative influence on carbon emissions, regulatory quality and the rule of law have a positive impact on emissions. Using data from 19 emerging countries over the period 1997–2010, Lv (2017) finds that though enhanced democracy is associated with a decrease in carbon emissions, it only does so when countries have reached certain high-income thresholds. In comparing 22 OECD countries to 87 non-OECD countries (over the period 1995–2010), Joshi and Beck (2018) find mixed results for the effect of democracy (political and economic freedom on carbon emissions. Regions of the countries drive the results. Using data on 46 SSA countries over the period 2000–2015 (Acheampong, Opoku, & Dzator, 2022), show that democracy drives carbon emissions. For a regional analysis, they find the direct effect of democracy on emissions to be positive in West Africa but negative for Southern, Central and Eastern Africa.

3. Methodology and data

3.1. Estimation strategy

In specifying the general empirical model, we follow and augment the EKC and the pollution haven hypotheses with the rural-urban energy equality variables as stated in equation (1):

$$ED_{i,t} = \alpha_0 + \beta_1 WDI_{i,t} + \beta_2 DEJ_{i,t} + \theta_1 X_{i,t} + \varepsilon_{i,t} \tag{1}$$

where $ED_{i,t}$ denotes the environmental degradation variables of country i at year t. $WDI_{\mathrm{i,t}}$ represents the governance indicators of country i at year t. $DEJ_{i,t}$ indicates the rural-urban energy equality variables of country i at year t. $X_{i,t}$ represents control variables included in the empirical model. The unknown coefficients to be estimated are represented by α_0, β_1, β_2 and θ_1. $\varepsilon_{\mathrm{i,t}}$ is the error term.

Equation (2) is formulated to estimate the interactive effect of rural-urban energy equality and governance on environmental degradation:

$$\ln ED_{i,t} = \alpha_0 + \beta_1 WDI_{i,t} + \beta_2 DEJ_{i,t} + \beta_3 (WDI \times DEJ)_{i,t} + \theta_1 X_{i,t} + \varepsilon_{i,t} \tag{2}$$

To test the conditional effect of rural-urban energy equality on environmental degradation, we used equation (3) to compute the marginal effect of rural-urban energy equality on the environment conditioned by governance.

$$\frac{\partial \ln ED}{\partial DEJ} = \beta_2 + (\beta_3 \times WDI) \tag{3}$$

To estimate the relationship among the variables specified in the above equations, we utilized the IV-Lewbel two-stage least squares (IV-Lewbel 2SLS) approach. This method is particularly useful in overcoming identification challenges that arise when appropriate external instruments are difficult to obtain or when instruments are weak or unavailable. By using the IV-Lewbel 2SLS estimator, we were able to identify structural parameters in the regression models, even when there is endogeneity or measurement error in the regressors, and traditional identifying information is not present (Lewbel, 2012). The IV-Lewbel 2SLS estimator employs internally constructed heteroskedasticity-based instruments, which are generated from the residuals of the auxiliary equation. These instruments are then multiplied by each of the included exogenous variables in mean-centred form. The resulting instruments help to address the identification challenges associated with endogenous or mismeasured regressors. The IV-Lewbel 2SLS estimator is particularly useful when external instruments are not available or are weak. Despite the use of internally constructed instruments, the IV-Lewbel 2SLS estimator generates estimates that are comparable to those obtained using external instruments (Lewbel, 2012). Apart from the IV-Lewbel 2SLS estimator, we also employed the Driscoll-Kraay estimator to estimate the relationship among the variables. The Driscoll-Kraay estimator is designed to handle heteroscedastic and autocorrelated error structures up to a certain lag, as well as a potential correlation between the panels. This estimation technique is robust to both cross-sectional and temporal dependence and can handle missing data series. The Driscoll-Kraay estimator is also suitable for use with both balanced and unbalanced panels, making it a versatile tool for econometric analysis (Driscoll & Kraay, 1998; Hoechle, 2007).

3.2. Description of Data

In this study, we constructed panel data comprising 47 SSA countries between 2000 and 2020.[1] The data used for the empirical analysis were retrieved data from World Development Indicators (WDI), World Governance Indicators (WGI), and the York University Ecological Footprint Initiative (YUEFI).

Three broad indicators of environmental degradation, namely, total greenhouse gas emissions, the ecological footprint of consumption, and the ecological footprint of production, were used as the dependent variables. We computed the rural-urban energy equality variable following Opoku and Acheampong (2023) and Trotter (2016). The two measures for assessing rural-urban equality in access to energy are determined by calculating the ratio of rural access to clean cooking fuels and electricity to urban access to these resources. A higher value indicates a

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[1] The SSA countries included in the analysis can be found in the Appendix Table.

greater degree of equality in access between rural and urban areas, while a lower value signifies a larger disparity in access. These measures are essential indicators of progress towards achieving sustainable energy for all, as higher levels of rural-urban equality in access to clean cooking fuels and electricity signify more sustainable and equitable energy access. To represent governance, we used the world governance indicators such as the rule of law, government effectiveness, control of corruption, regulatory quality, voice and accountability, and political stability. These governance indicators range from − 2.5 to 2.5, with higher values corresponding to better governance outcomes and vice versa (see, Kaufmann, Kraay, & Mastruzzi, 2011).

We controlled for GDP per capita, GDP per capita squared, financial development, trade openness, and foreign direct investment. The inclusion of these variables is consistent with the literature on the determinants of environmental degradation (Apergis & Ozturk, 2015a; Evans & Mesagan, 2022; Pal & Mitra, 2017; Sethi, Chakrabarti, & Bhattacharjee, 2020). Table 1 presents the descriptive statistics, proxies, and sources of data for the variables used in the study. The variables, except for the governance indicators, underwent a log-transformation.

4. Results

In this section, we discuss the empirical findings. Tables 2–4 respectively report the regression results on the direct effects of rural-urban energy equality and governance on total greenhouse gas emissions, ecological footprint of production, and ecological footprint of consumption based on the Lewbel 2SLS estimator. In Table 2, we find that rural-urban energy equality inhibits total greenhouse gas emissions. This finding is supported by the negative and statistically significant coefficients (at 1% level) of rural-urban equality in access to clean cooking fuels and technologies and access to electricity in all models, ceteris paribus. Precisely, a percentage rise in rural-urban equality in access to clean cooking fuels and technologies result in a reduction in total greenhouse gas emissions by between 0.335% and 0.631%, ceteris paribus. Likewise, there is a decline in total greenhouse gas emissions by 0.355–0.474% when there is a percentage increase in the equality of the rural and urban population in terms of access to electricity, ceteris paribus. Concerning governance, the coefficients of political stability are negative and statistically significant at 1% level, and this suggests that increase in political stability leads to lower greenhouse gas emissions, ceteris paribus. However, regulatory quality has negative coefficients albeit only statistically significant (at 1% level) when rural-urban energy equality is represented by rural-urban equality in access to clean cooking fuels and technologies (see Model 3, Table 2). Also, the coefficients of voice and accountability are positive and statistically significant at 1% level. Rule of law and government effectiveness do not exert any influence on total greenhouse emissions because they enter the models with statistically insignificant coefficients (see Models 5, 6, 9, and 10 in Table 2). The coefficients of control of corruption are negative and statistically significant at 1% level (see Models 11–12), suggesting that controlling corruption serves as important medium for addressing the emissions of greenhouse gases, ceteris paribus.

With respect to ecological footprint, we offer strong support for the role of rural-urban energy equality in reducing ecological footprint of production and consumption (see Tables 3 and 4). This stems from the negative and statistically significant coefficients (at 1% level) exhibited by the rural-urban energy equality measures in all the models. From Table 3, we observe that a percentage increase in rural-urban equality in access to clean cooking fuels and technologies cause ecological footprint of production to fall by between 0.231% and 0.636% whilst ecological footprint of consumption also decreases by 0.193–0.504%, ceteris paribus. A 0.317–0.428% reduction in ecological footprint of production is the consequence of a percentage increase in rural-urban equality in access to electricity. In Table 4, the results indicate

Table 1
Descriptive statistics, variable proxies, and sources.

Variable	Proxies	Mean	Std. Dev.	Min	Max	Sources
Total greenhouse gas emissions	Total greenhouse gas emissions (kt of CO2 equivalent)	9.441	1.676	4.248	13.237	WDI
Ecological footprint of production	Ecological footprint of production (total global hectares)	16.025	1.424	11.99	19.147	YUEFI
Ecological footprint of consumption	Ecological footprint of consumption (total global hectares)	16.121	1.375	12.076	19.15	
Rural-urban energy equality (clean)	Ratio of rural to urban access to clean fuels and technologies for cooking	-2.013	1.044	-4.963	.693	Authors' computation from WDI
Rural-urban energy equality (electricity)	Ratio of rural to urban access to electricity	-1.637	1.045	-4.887	.036	
Control of corruption	Control of corruption score	-.63	.642	-1.849	1.42	WGI
Political stability	Political Stability and Absence of Violence/Terrorism score	-.552	.919	-3.313	1.283	
Regulatory quality	Regulatory quality score	-.711	.639	-2.548	1.197	
Rule of law	Rule of law score	-.712	.659	-2.591	1.024	
Voice and accountability	Voice and accountability score	-.589	.753	-2.226	.983	
Government effectiveness	Government effectiveness score	-.784	.629	-2.445	1.161	
GDP per capita	GDP per capita (constant 2010 US$)	11.854	2.133	6.113	16.053	WDI
GDP per capita squared	GDP per capita (constant 2010 US$) squared	145.059	48.065	37.366	257.691	
Financial development	Domestic credit to private sector (% of GDP)	2.593	.863	-.91	4.959	
Trade openness	Trade (% of GDP)	4.11	.579	-.279	5.416	
Foreign direct investment	Net inflows of foreign direct investment (% of GDP)	.878	1.348	-6.166	4.638	

Table 2
Rural-urban energy equality, Governance and Total Greenhouse Gas Emissions [IV-Lewbel 2SLS].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
GDP per capita	-1.370***	-1.355***	-2.113***	-1.493***	-1.490***	-1.403***	-2.313***	-1.871***	-1.742***	-1.417***	-0.861***	-1.167***
	(0.196)	(0.203)	(0.241)	(0.225)	(0.221)	(0.214)	(0.236)	(0.262)	(0.240)	(0.222)	(0.253)	(0.220)
GDP per capita square	0.063***	0.062***	0.093***	0.067***	0.067***	0.063***	0.102***	0.083***	0.078***	0.064***	0.038***	0.052***
	(0.008)	(0.009)	(0.010)	(0.010)	(0.010)	(0.009)	(0.010)	(0.011)	(0.010)	(0.010)	(0.011)	(0.010)
Financial development	0.737***	0.770***	0.183	0.571***	0.666***	0.761***	0.217*	0.356***	0.341*	0.739***	0.997***	0.873***
	(0.091)	(0.122)	(0.136)	(0.157)	(0.151)	(0.154)	(0.112)	(0.136)	(0.194)	(0.198)	(0.138)	(0.142)
Trade openness	-0.508***	-0.671***	-0.952***	-0.952***	-0.862***	-0.899***	-0.937***	-0.984***	-0.986***	-0.892***	-0.587***	-0.765***
	(0.131)	(0.144)	(0.119)	(0.138)	(0.120)	(0.133)	(0.114)	(0.133)	(0.139)	(0.147)	(0.120)	(0.122)
Foreign direct investment	0.183***	0.108**	0.066	0.061	0.152***	0.101	0.067	0.018	0.098*	0.091	0.204***	0.114**
	(0.046)	(0.055)	(0.043)	(0.059)	(0.051)	(0.062)	(0.047)	(0.058)	(0.051)	(0.062)	(0.050)	(0.055)
Rural-urban eq. (Clean)	-0.335***		-0.631***		-0.413***		-0.617***		-0.565***		-0.238***	
	(0.057)		(0.060)		(0.068)		(0.049)		(0.081)		(0.068)	
Rural-urban eq. electricity)		-0.355***		-0.415***		-0.361***		-0.474***		-0.375***		-0.320***
		(0.066)		(0.069)		(0.075)		(0.074)		(0.083)		(0.070)
Political stability	-0.827***	-0.526***										
	(0.186)	(0.177)										
Regulatory quality			0.960***	0.106								
			(0.287)	(0.231)								
Rule of law					-0.419	-0.367						
					(0.300)	(0.256)						
Voice and accountability							0.826***	0.625***				
							(0.169)	(0.167)				
government effectiveness									0.489	-0.284		
									(0.419)	(0.340)		
Control of corruption											-1.579***	-0.778***
											(0.331)	(0.227)
Constant	15.575***	16.463***	23.820***	19.295***	18.029***	17.773***	24.595***	22.384***	21.168***	17.932***	12.540***	15.657***
	(1.331)	(1.414)	(1.601)	(1.484)	(1.523)	(1.232)	(1.430)	(1.576)	(1.959)	(1.513)	(1.669)	(1.254)
Observations	672	598	672	598	672	598	672	598	671	597	672	598
R2	0.337	0.328	0.256	0.227	0.262	0.255	0.200	0.187	0.246	0.215	0.273	0.317

Standard errors in parentheses* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3
Rural-urban energy equality, Governance and Ecological Footprint of Production [IV-Lewbel 2SLS].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
GDP per capita	-0.552 * *	-0.707 * *	-1.163 * **	-0.923 * **	-0.429	-0.694 * *	-1.717 * **	-1.507 * **	-0.628 * *	-0.675 * *	0.087	-0.461
	(0.269)	(0.314)	(0.286)	(0.331)	(0.335)	(0.330)	(0.269)	(0.322)	(0.290)	(0.334)	(0.364)	(0.339)
GDP per capita square	0.026 * *	0.032 * *	0.051 * **	0.040 * **	0.020	0.032 * *	0.076 * **	0.065 * **	0.029 * *	0.031 * *	-0.005	0.020
	(0.011)	(0.013)	(0.012)	(0.014)	(0.014)	(0.014)	(0.012)	(0.014)	(0.012)	(0.014)	(0.016)	(0.015)
Financial development	0.564 * **	0.563 * **	0.015	0.249 *	0.631 * **	0.699 * **	-0.071	-0.031	0.247	0.641 * **	0.863 * **	0.805 * **
	(0.088)	(0.128)	(0.117)	(0.135)	(0.161)	(0.147)	(0.103)	(0.138)	(0.179)	(0.207)	(0.114)	(0.123)
Trade openness	-0.677 * **	-0.956 * **	-1.123 * **	-1.105 * **	-0.977 * **	-1.000 * **	-1.124 * **	-1.138 * **	-1.108 * **	-1.020 * **	-0.775 * **	-0.890 * **
	(0.163)	(0.191)	(0.143)	(0.166)	(0.154)	(0.162)	(0.132)	(0.160)	(0.153)	(0.180)	(0.168)	(0.160)
Foreign direct investment	0.148 * **	0.073	0.041	0.029	0.157 * **	0.100 *	0.026	-0.023	0.097 * *	0.082	0.180 * **	0.098 *
	(0.041)	(0.055)	(0.044)	(0.053)	(0.052)	(0.056)	(0.049)	(0.058)	(0.047)	(0.058)	(0.049)	(0.052)
Rural-urban eq. (Clean)	-0.246 * **		-0.556 * **		-0.231 * **		-0.636 * **		-0.424 * **		-0.107	
	(0.056)		(0.063)		(0.086)		(0.061)		(0.078)		(0.077)	
Rural-urban eq. (electricity)		-0.311 * **		-0.350 * **		-0.281 * **		-0.420 * **		-0.298 * **		-0.271 * **
		(0.065)		(0.065)		(0.068)		(0.075)		(0.073)		(0.067)
Political stability	-0.736 * **	-0.179										
	(0.177)	(0.227)										
Regulatory quality			1.095 * **	0.644 * **								
			(0.255)	(0.208)								
Rule of law					-0.758 * *	-0.459 *						
					(0.379)	(0.243)						
Voice and accountability							1.333 * **	1.266 * **				
							(0.150)	(0.176)				
government effectiveness									0.371	-0.295		
									(0.443)	(0.407)		
Control of corruption											-1.713 * **	-0.851 * **
											(0.308)	(0.215)
Constant	19.248 * **	21.569 * **	26.630 * **	24.816 * **	19.552 * **	21.104 * **	29.779 * **	29.208 * **	22.597 * **	21.341 * **	15.413 * **	19.146 * **
	(1.818)	(2.107)	(1.945)	(2.253)	(2.433)	(2.103)	(1.695)	(2.097)	(2.148)	(2.447)	(2.378)	(2.119)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.329	0.251	0.216	0.213	0.197	0.221	0.057	0.038	0.208	0.173	0.108	0.254

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

Table 4
Rural-urban energy equality, Governance and Ecological Footprint of Consumption [IV-Lewbel 2SLS].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
GDP per capita	-0.393	-0.577 *	-1.004 * **	-0.804 * *	-0.361	-0.564 *	-1.515 * **	-1.343 * **	-0.528 *	-0.550 *	0.220	-0.336
	(0.263)	(0.302)	(0.277)	(0.319)	(0.311)	(0.319)	(0.255)	(0.307)	(0.281)	(0.317)	(0.358)	(0.330)
GDP per capita square	0.018 *	0.026 * *	0.044 * **	0.035 * *	0.017	0.025 *	0.066 * **	0.058 * **	0.024 * *	0.025 *	-0.012	0.014
	(0.011)	(0.013)	(0.012)	(0.014)	(0.013)	(0.014)	(0.011)	(0.013)	(0.012)	(0.014)	(0.016)	(0.014)
Financial development	0.594 * **	0.609 * **	0.043	0.268 * *	0.514 * **	0.651 * **	-0.026	0.024	0.155	0.548 * **	0.872 * **	0.831 * **
	(0.082)	(0.116)	(0.114)	(0.130)	(0.147)	(0.138)	(0.099)	(0.130)	(0.173)	(0.194)	(0.108)	(0.114)
Trade openness	-0.631 * **	-0.891 * **	-1.081 * **	-1.067 * **	-0.983 * **	-0.984 * **	-1.080 * **	-1.094 * **	-1.110 * **	-1.018 * **	-0.744 * **	-0.853 * **
	(0.153)	(0.176)	(0.137)	(0.158)	(0.147)	(0.155)	(0.124)	(0.150)	(0.143)	(0.168)	(0.159)	(0.151)
Foreign direct investment	0.165 * **	0.094 *	0.058	0.046	0.144 * **	0.103 *	0.045	-0.001	0.102 * *	0.087	0.194 * **	0.116 * *
	(0.041)	(0.054)	(0.044)	(0.053)	(0.049)	(0.054)	(0.048)	(0.057)	(0.046)	(0.055)	(0.048)	(0.051)
Rural-urban eq. (Clean)	-0.193 * **		-0.504 * **		-0.258 * **		-0.574 * **		-0.423 * **		-0.065	
	(0.055)		(0.060)		(0.079)		(0.056)		(0.075)		(0.074)	
Rural-urban eq. (electricity)		-0.269 * **		-0.312 * **		-0.258 * **		-0.376 * **		-0.277 * **		-0.233 * **
		(0.062)		(0.062)		(0.066)		(0.071)		(0.069)		(0.064)
Political stability	-0.746 * **	-0.220										
	(0.172)	(0.215)										
Regulatory quality			1.094 * **	0.683 * **								
			(0.253)	(0.206)								
Rule of law					-0.336	-0.262						
					(0.339)	(0.230)						
Voice and accountability							1.281 * **	1.217 * **				
							(0.142)	(0.166)				
government effectiveness									0.710 *	0.004		
									(0.414)	(0.375)		
Control of corruption											-1.649 * **	-0.826 * **
											(0.299)	(0.210)
Constant	18.390 * **	20.672 * **	25.800 * **	24.219 * **	19.933 * **	20.809 * **	28.637 * **	28.175 * **	22.709 * **	21.317 * **	14.820 * **	18.477 * **
	(1.747)	(1.993)	(1.846)	(2.123)	(2.215)	(1.985)	(1.575)	(1.959)	(1.999)	(2.258)	(2.280)	(2.012)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.315	0.260	0.214	0.219	0.196	0.209	0.071	0.064	0.201	0.195	0.098	0.251

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

that ecological footprint of consumption reduces by 0.193–0.574% when the rural-urban equality in access to clean cooking fuels and technologies improves by a percentage, ceteris paribus. Similarly, a percentage increase in rural-urban equality in access to electricity leads to a 0.269–0.376%, ceteris paribus. As shown in Tables 3, political stability has negative coefficients, but it is statistically significant (at 1% level) in Model 1 only. Considering rural-urban equality in the access to clean cooking fuels and technologies, increased stability in the political environment diminishes ecological footprint of production. Similar finding is observed in Table 4 for ecological footprint of consumption. The coefficients of regulatory quality are positive and statistically significant at 1% level in Tables 3 and 4. The negative and statistically significant coefficients of rule of law as seen in Table 3 suggests that stronger rule of law could lead to a reduction in the ecological footprint of production. However, in Table 4, rule of law does not matter for ecological footprint of consumption because its coefficients do not exhibit statistical significance at the conventional levels. Voice and accountability has positive and statistically significant coefficients in Tables 3 and 4, indicating that increased voice and accountability is associated with rise in ecological footprint in terms of production and consumption. Ecological footprint of production does not respond to changes in government because the coefficients of government effectiveness appear not statistically significant (see Table 3). However, we show that ecological footprint of consumption tends to increase as result of an increase in government effectiveness. This is because government effectiveness has a positive and statistically significant coefficient (at 10% level) in Model 9 of Table 4. The coefficients of control of corruption are negative and statistically significant at 1% level (see Models 11–12), indicating that improvement in corruption control mitigate ecological footprint of production.

Turning to the results obtained for the control variables in Tables 2–4, we largely find that GDP per capita has negative and statistically significant effect on total greenhouse gas emissions, ecological footprint of production, and ecological footprint of consumption. Contrary to theoretical expectation, this finding suggests that higher income or affluence fosters environmental sustainability. Similarly, the coefficients of GDP per capita^2 are mostly found to be positive and statistically significant at the conventional levels and this portrays that the relationship between income and environmental sustainability is U-shaped. This U-shaped relationship, which negates the postulation of the EKC hypothesis, suggests that a rise in income initially promotes environmental sustainability but the environment would become less sustainable due to a further rise in income when income exceeds a certain threshold level. Financial development is found to largely have positive and statistically significant coefficients, and this connotes that better developed financial sector seems not to enhance environmental sustainability. The coefficients of trade openness are consistently negative and statistically significant at 1% level, suggesting that improved environmental sustainability is associated with more openness to trade. On the contrary, we find that more openness to foreign direct investment hinders environmental sustainability because the coefficients of foreign direct investment are largely found to be positive and statistically significant.

4.1. Robustness check

We consider the Driscoll-Kraay estimator as an alternative estimation strategy to check for the robustness of our earlier findings. The Driscoll-Kraay estimator caters for potential cross-sectional dependence in the models. The regression results of the robustness check are presented in Tables 5–7. The findings obtained from these tables are largely in tandem with our earlier

Table 5
Rural-urban energy equality, Governance and Total Greenhouse Gas Emissions [Driscol-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (Clean)	-0.353 * **		-0.572 * **		-0.397 * **		-0.519 * **		-0.530 * **		-0.345 * **	
	(0.042)		(0.053)		(0.027)		(0.028)		(0.033)		(0.023)	
Political stability	-0.730 * **	-0.824 * **										
	(0.099)	(0.047)										
Rural-urban eq. (electricity)		-0.325 * **		-0.428 * **		-0.317 * **		-0.417 * **		-0.411 * **		-0.290 * **
		(0.037)		(0.045)		(0.030)		(0.050)		(0.044)		(0.023)
Regulatory quality			0.566 * **	0.282 * **								
			(0.193)	(0.087)								
Rule of law					-0.510 * **	-0.714 * **						
					(0.029)	(0.094)						
Voice and accountability							0.204 * **	0.096 *				
							(0.068)	(0.052)				
government effectiveness									0.282 *	0.047		
									(0.136)	(0.054)		
Control of corruption											-0.901 * **	-1.048 * **
											(0.041)	(0.108)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	16.042 * **	15.096 * **	22.061 * **	20.002 * **	17.700 * **	16.732 * **	20.780 * **	19.408 * **	20.438 * **	18.935 * **	15.543 * **	14.543 * **
	(0.979)	(0.688)	(2.692)	(2.529)	(1.475)	(1.352)	(2.065)	(1.900)	(2.134)	(2.091)	(1.258)	(1.161)
Observations	672	598	672	598	672	598	672	598	671	597	672	598
R2	0.339	0.344	0.267	0.229	0.262	0.265	0.248	0.224	0.249	0.224	0.313	0.324

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

Table 6
Rural-urban energy equality, Governance and Ecological Footprint of Production [Driscol-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (Clean)	-0.246 * **		-0.480 * **		-0.300 * **		-0.446 * **		-0.424 * **		-0.275 * **	
	(0.035)		(0.041)		(0.042)		(0.026)		(0.026)		(0.040)	
Political stability	-0.736 * **	-0.765 * **										
	(0.058)	(0.038)										
Rural-urban eq. (electricity)		-0.284 * **		-0.341 * **		-0.279 * **		-0.342 * **		-0.332 * **		-0.278 * **
		(0.077)		(0.024)		(0.047)		(0.023)		(0.026)		(0.054)
Regulatory quality			0.639 * **	0.449 * **								
			(0.108)	(0.079)								
Rule of law					-0.390 * **	-0.488 * **						
					(0.090)	(0.132)						
Voice and accountability							0.368 * **	0.295 * **				
							(0.020)	(0.082)				
government effectiveness									0.374 * **	0.246 * **		
									(0.082)	(0.033)		
Control of corruption											-0.630 * **	-0.722 * **
											(0.116)	(0.148)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	19.251 * **	19.570 * **	24.584 * **	24.015 * **	20.605 * **	21.037 * **	23.947 * **	23.813 * **	22.604 * **	22.637 * **	19.399 * **	19.604 * **
	(1.241)	(1.508)	(1.976)	(2.524)	(1.289)	(1.724)	(1.540)	(1.838)	(1.609)	(2.118)	(1.379)	(1.698)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.329	0.332	0.238	0.217	0.210	0.221	0.219	0.209	0.208	0.200	0.240	0.256

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

Table 7
Rural-urban energy equality, Governance and Ecological Footprint of Consumption [Driscol-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (Clean)	-0.202 * **		-0.430 * **		-0.266 * **		-0.400 * **		-0.385 * **		-0.227 * **	
	(0.038)		(0.046)		(0.046)		(0.025)		(0.026)		(0.046)	
Political stability	-0.691 * **	-0.698 * **										
	(0.056)	(0.041)										
Rural-urban eq. (electricity)		-0.247 * **		-0.303 * **		-0.249 * **		-0.307 * **		-0.299 * **		-0.241 * **
		(0.068)		(0.026)		(0.042)		(0.024)		(0.026)		(0.049)
Regulatory quality			0.652 * **	0.490 * **								
			(0.110)	(0.086)								
Rule of law					-0.291 * **	-0.370 * **						
					(0.078)	(0.110)						
Voice and accountability							0.400 * **	0.343 * **				
							(0.012)	(0.062)				
government effectiveness									0.454 * **	0.346 * **		
									(0.069)	(0.027)		
Control of corruption											-0.605 * **	-0.681 * **
											(0.100)	(0.123)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	18.575 * **	19.041 * **	23.820 * **	23.426 * **	20.060 * **	20.556 * **	23.312 * **	23.326 * **	22.011 * **	22.137 * **	18.667 * **	18.995 * **
	(0.901)	(1.163)	(1.575)	(2.080)	(0.994)	(1.406)	(1.244)	(1.549)	(1.223)	(1.720)	(1.064)	(1.361)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.316	0.320	0.236	0.224	0.197	0.210	0.218	0.217	0.208	0.207	0.232	0.254

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

findings. To recall, we consistently demonstrate that increase in both measures of rural-urban energy equality reduce total greenhouse gas emissions, ecological footprint of production, and ecological footprint of consumption. Our earlier deductions from Tables 2–4 are also validated by the robustness check. Our earlier submissions based on the findings obtained for the control variables in Tables 2–4 remain similar to those presented here. Thus, the consistency of our earlier findings with the robustness check is further attested. Overall, the strong similarity of earlier findings with those emerging from the robustness check exercise prompt us to reason along the line of thought that our earlier findings are not biased by cross-sectional dependence that may be present in the models.

4.2. Analysis of the Interactions between rural-urban energy equality and governance on environment

We now probe the conditional role of governance in the rural-urban energy equality-environmental sustainability nexus by accounting for the moderating effect of governance on the role of rural-urban energy equality in environmental sustainability. To do this, we interact the governance indicators with the rural-urban energy equality measures. The effects of these interactions are obtained using the Driscoll-Kraay estimator. Tables 8–10 report the regression results with respect to the moderating (interactive) effects. Due to the consistency of the direct effects in these tables with our earlier findings, we focus our attention mainly on the interactions. The direct effects show how the rural-urban energy equality measures relate to the environmental sustainability measures in the absence of governance. In Table 8, we find that the effect of rural-urban energy equality on total greenhouse gas emissions is moderated by political stability only when rural-urban equality in access to electricity is taken as the measure of rural-urban energy equality. The coefficient of the interaction between rural-urban equality in access to electricity and political stability is negative and statistically significant at 1% level and this suggests that increase in rural-urban equality in access to electricity reduces total greenhouse gas emissions in the presence of political stability. However, political stability appears to have weakened the reducing effect of rural-urban equality in access to electricity on total greenhouse gas emissions. This is because, in the absence of the moderating effect of political stability, rural-urban equality in access to electricity has greater reducing effect on total greenhouse gas emissions.

The coefficients of the interactions between both energy measures and regulatory quality are positive and statistically significant at 1% level. This suggests that regulatory quality stalls the ability of rural-urban energy equality to reduce total greenhouse gas emissions; rather it makes rural-urban energy equality a contributing factor of total greenhouse gas emissions. We find that rule of law and voice and accountability positively and negatively moderate the effect of rural-urban energy equality on total greenhouse gas emissions depending on the measure of rural-urban energy equality. On the one hand, their interactions with rural-urban equality in access to cooking fuels and technologies yield positive and statistically significant coefficients and this suggests that rural-urban equality in access to cooking fuels and technologies increases emissions of greenhouse gases in the presence of rule of law and voice and accountability. On the other hand, in the presence of rule of law and voice and accountability, rural-urban equality in access to electricity maintains its ability to reduce greenhouse gas emissions albeit at a diminishing rate.

In case of government effectiveness, we obtain a positive and statistically significant coefficient on its interaction with rural-urban equality in access to cooking fuels and technologies.

Table 8
Interactive effect of Rural-urban energy equality and Governance on Total Greenhouse Gas Emissions [Driscol-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (electricity)		-0.510 * ** (0.037)		-0.222 * * (0.077)		-0.447 * ** (0.041)		-0.503 * ** (0.045)		-0.333 * ** (0.087)		-0.489 * ** (0.087)
Political stability	-0.675 * ** (0.065)	-1.671 * ** (0.071)										
Regulatory quality			0.994 * ** (0.172)	0.742 * ** (0.195)								
Rule of law					-0.399 * ** (0.031)	-1.001 * ** (0.085)						
Voice and accountability							0.411 * ** (0.071)	-0.153 (0.114)				
Government effectiveness									0.378 * ** (0.114)	0.160 * * (0.065)		
Control of corruption											-0.664 * ** (0.152)	-1.551 * ** (0.101)
Rural-urban eq. (Clean) × Political stability	0.029 (0.021)											
Rural-urban eq. (electricity) × Political stability		-0.472 * ** (0.019)										
Rural-urban eq. (Clean) × Regulatory quality			0.223 * ** (0.030)									
Rural-urban eq. (electricity) × Regulatory quality				0.319 * ** (0.088)								
Rural-urban eq. (Clean) × Rule of law					0.064 * ** (0.012)							
Rural-urban eq. (electricity) × Rule of law						-0.193 * ** (0.017)						
Rural-urban eq. (Clean) × Voice and accountability							0.107 * (0.053)					

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Table 8 (*continued*)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (electricity) × Voice and accountability								-0.160 * **				
								(0.044)				
Rural-urban eq. (Clean) × Government effectiveness									0.065 * **			
									(0.017)			
Rural-urban eq. (electricity) × Government effectiveness										0.097		
										(0.068)		
Rural-urban eq. (Clean) × Control of corruption											0.132	
											(0.107)	
Rural-urban eq. (electricity) × Control of corruption												-0.338 * **
												(0.106)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	16.371 * **	12.176 * **	23.587 * **	20.445 * **	18.147 * **	16.293 * **	21.678 * **	19.156 * **	20.862 * **	19.177 * **	16.565 * **	13.616 * **
	(0.837)	(1.174)	(2.658)	(2.698)	(1.508)	(1.366)	(1.717)	(1.844)	(2.086)	(2.242)	(2.073)	(1.292)
Marginal effects of rural-urban energy equality when governance indicators scores are at their maximum (2.5)												
Rural-urban eq. variables	-0.262 * **	-1.690 * **	0.132	0.577 *	-0.191 * **	-0.930 * **	-0.190	-0.903 * **	-0.316 * **	-0.090	0.061	-1.336 * **
	(0.098)	(0.075)	(0.117)	(0.295)	(0.060)	(.067)	(0.185)	(0.082)	(.078)	(0.257)	(0.345)	(0.352)
Observations	672	598	672	598	672	598	672	598	671	597	672	598
R2	0.339	0.400	0.275	0.240	0.263	0.270	0.251	0.228	0.250	0.225	0.315	0.338

Standard errors in parentheses.* $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

Table 9
Interactive effect of Rural-urban energy equality and Governance on Ecological Footprint of Production [Driscoll-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (Clean)	-0.268 * **		-0.541 * **		-0.446 * **		-0.535 * **		-0.529 * **		-0.262	
	(0.037)		(0.049)		(0.068)		(0.033)		(0.033)		(0.159)	
Rural-urban eq. (electricity)		-0.501 * **		-0.303 * **		-0.524 * **		-0.486 * **		-0.374 * **		-0.513 * **
		(0.049)		(0.080)		(0.043)		(0.020)		(0.064)		(0.092)
Political stability	-0.794 * **	-1.680 * **										
	(0.078)	(0.054)										
Regulatory quality			0.476 * **	0.539 * *								
			(0.131)	(0.221)								
Rule of law					-0.697 * **	-1.054 * **						
					(0.069)	(0.087)						
Voice and accountability							0.077	-0.171				
							(0.083)	(0.110)				
Government effectiveness									0.195	0.178 *		
									(0.156)	(0.097)		
Control of corruption											-0.598 * *	-1.365 * **
											(0.223)	(0.088)
Rural-urban eq. (Clean) × Political stability	-0.031 *											
	(0.017)											
Rural-urban eq. (electricity) × Political stability		-0.507 * **										
		(0.017)										
Rural-urban eq. (Clean) × Regulatory quality			-0.083 *									
			(0.040)									
Rural-urban eq. (electricity) × Regulatory quality				0.062								
				(0.125)								
Rural-urban eq. (Clean) × Rule of law					-0.180 * **							
					(0.059)							
Rural-urban eq. (electricity) × Rule of law						-0.377 * **						
						(0.035)						
Rural-urban eq. (Clean) × Voice and accountability							-0.148 * **					

(*continued on next page*)

Table 9 (*continued*)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
							(0.037)					
Rural-urban eq. (electricity) × Voice and accountability								-0.301 * **				
								(0.026)				
Rural-urban eq. (Clean) × Government effectiveness									-0.118 * *			
									(0.052)			
Rural-urban eq. (electricity) × Government effectiveness										-0.052		
										(0.081)		
Rural-urban eq. (Clean) × Control of corruption											0.018	
											(0.185)	
Rural-urban eq. (electricity) × Control of corruption												-0.405 * **
												(0.136)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	18.885 * **	16.833 * **	24.028 * **	24.085 * **	19.252 * **	20.285 * **	22.633 * **	23.400 * **	21.779 * **	22.501 * **	19.547 * **	18.487 * **
	(1.253)	(2.234)	(2.124)	(2.659)	(1.462)	(1.724)	(1.328)	(1.869)	(1.828)	(2.299)	(2.871)	(1.941)
Marginal effects of rural-urban energy equality when governance indicators scores are at their maximum (2.5)												
Rural-urban eq. variables	-0.345 * **	-1.768 * **	-0.749 * **	-0.147	-0.897 * **	-1.465 * **	-0.906 * **	-1.237 * **	-0.825 * **	-0.504 * **	-0.217	-1.527 * **
	(0.065)	(0.056)	(0.134)	(0.389)	(0.212)	(0.111)	(0.116)	(0.062)	(0.159)	(0.264)	(0.619)	(0.425)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.330	0.411	0.240	0.218	0.218	0.244	0.225	0.229	0.211	0.201	0.240	0.277

Standard errors in parentheses. * $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

Table 10
Interactive effect of rural-urban energy equality and Governance on Ecological Footprint of Consumption [Driscoll-Kraay Results].

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Rural-urban eq. (Clean)	-0.180***		-0.429***		-0.331***		-0.449***		-0.410***		-0.165	
	(0.048)		(0.061)		(0.089)		(0.026)		(0.054)		(0.177)	
Rural-urban eq. (electricity)		-0.432***		-0.219**		-0.425***		-0.426***		-0.281***		-0.457***
		(0.050)		(0.087)		(0.057)		(0.037)		(0.077)		(0.110)
Political stability	-0.630***	-1.478***										
	(0.091)	(0.085)										
Regulatory quality			0.654***	0.691***								
			(0.110)	(0.200)								
Rule of law					-0.427***	-0.777***						
					(0.072)	(0.033)						
Voice and accountability							0.240***	-0.044				
							(0.060)	(0.049)				
Government effectiveness									0.410**	0.376***		
									(0.146)	(0.108)		
Control of corruption											-0.445	-1.270***
											(0.260)	(0.147)
Rural-urban eq. (Clean) × Political stability	0.032											
	(0.023)											
Rural-urban eq. (electricity) × Political stability		-0.432***										
		(0.026)										
Rural-urban eq. (Clean) × Regulatory quality			0.001									
			(0.037)									
Rural-urban eq. (electricity) × Regulatory quality				0.138								
				(0.123)								
Rural-urban eq. (Clean) × Rule of law					-0.079							
					(0.069)							
Rural-urban eq. (electricity) × Rule of law						-0.271***						
						(0.056)						
Rural-urban eq. (Clean) × Voice and accountability							-0.081**					

(continued on next page)

Table 10 (*continued*)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
							(0.032)					
Rural-urban eq. (electricity) × Voice and accountability								-0.250 * **				
								(0.026)				
Rural-urban eq. (Clean) ×government effectiveness									-0.029			
									(0.060)			
Rural-urban eq. (electricity) × government effectiveness										0.023		
										(0.089)		
Rural-urban eq. (Clean) × Control of corruption											0.088	
											(0.200)	
Rural-urban eq. (electricity) × Control of corruption												-0.372 * *
												(0.160)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	18.952 * **	16.708 * **	23.824 * **	23.582 * **	19.465 * **	20.014 * **	22.593 * **	22.983 * **	21.812 * **	22.197 * **	19.394 * **	17.970 * **
	(1.048)	(1.858)	(1.685)	(2.210)	(1.347)	(1.464)	(1.207)	(1.609)	(1.569)	(1.938)	(2.737)	(1.672)
Marginal effects of rural-urban energy equalit when governance indicators scores are at their maximum (2.5)												
Rural-urban eq. variables	-0.100	-1.512 * **	-0.428 * **	0.127	-0.529	-1.102 * **	-0.652 * **	-1.050 * **	-0.481 * *	-0.223	0.056	-1.387 * **
	(0.097)	(0.088)	(0.142)	(0.390)	(0.259)	(0.185)	(0.094)	(0.092)	(0.200)	(0.296)	(0.675)	(0.503)
Observations	538	479	538	479	538	479	538	479	537	478	538	479
R2	0.317	0.383	0.236	0.227	0.198	0.223	0.220	0.231	0.208	0.207	0.234	0.274

Standard errors in parentheses. * $p < 0.10$, * * $p < 0.05$, * ** $p < 0.01$

This implies that rural-urban equality in access to cooking fuels and technologies heightens greenhouse gas emissions in the face of government effectiveness. However, rural-urban equality in access to electricity loses its power to reduce greenhouse gas emissions when government effectiveness is present. In addition, the coefficient on interaction between control of corruption and rural-urban equality in access to cooking fuels and technologies is positive and statistically insignificant [see Model 11]. However, in Model 12, the coefficient of the interaction between rural-urban equality in access to electricity and control of corruption is negative and statistically significant at 1% level and this suggests that increase in rural-urban equality in access to electricity reduces total greenhouse gas emissions in the presence of control of corruption. In sum, the marginal effect analysis suggests that with improvement in governance variables such as political stability, rule of law, voice and accountability, control of corruption and government effectiveness to their maximum level, rural-urban energy equality is associated with a reduction in greenhouse gas emissions.

From Table 9, the coefficients of the interaction between the measures of rural-urban energy equality and political stability, rule of law, and voice and accountability are negative and statistically significant at 1% level, and this indicates that rural-urban energy equality is negatively associated with ecological footprint of production in the presence of these governance indicators. However, we notice that negative association is stronger in the absence of political stability, rule of law, and voice and accountability. When regulatory quality is interacted with rural-urban energy equality measures, positive and statistically significant coefficients at 1% level are obtained. These coefficients indicate that regulatory quality moderate the effect of rural-urban energy equality on ecological footprint of production in a detrimental manner. The implication of this is that, regardless of the measure of rural-urban energy equality, regulatory quality gives rise to a stimulating effect of rural-urban energy equality on ecological footprint of production. We also find that the effect of rural-urban energy equality on ecological footprint of production is moderated by government effectiveness only when rural-urban energy equality is measured by rural-urban equality in access to clean cooking fuels and technologies.

The coefficient of the interaction between rural-urban equality in access to clean cooking fuels and technologies and government effectiveness is negative and statistically significant at 5% level. This suggests that rural-urban equality in access to clean cooking fuels and technologies reduces ecological footprint of production in the presence of government effectiveness. However, we observe that rural-urban equality in access to clean cooking fuels and technologies would have a stronger reducing effect when regulatory quality is not present. This connotes that regulatory quality dampens the mitigating role of rural-urban equality in access to clean cooking fuels and technologies in reducing ecological footprint of production. In addition, the coefficient on interaction between control of corruption and rural-urban equality in access to cooking fuels and technologies on ecological footprint of production is positive and statistically insignificant [see Model 11]. However, in Model 12, the coefficient of the interaction between rural-urban equality in access to electricity and control of corruption on ecological footprint of production is negative and statistically significant at 1% level and this suggests that increase in rural-urban equality in access to electricity is associated with a reduction in ecological footprint of production in the presence of control of corruption. In general, the marginal effect results show that governance indicators reinforce the role of rural-urban energy equality to substantially reduce ecological footprint of production.

As seen in Table 10, while the coefficient of the interaction between rural-urban equality in access to clean cooking fuels and technologies and political stability is positive but not statistically significant, the interaction between rural-urban equality in access to electricity yields a negative and statistically significant coefficient at 1% level and this suggests that political stability aids rural-urban energy equality in form of rural-urban equality in access to electricity to reduce ecological footprint of consumption. Nevertheless, it is apparent from Table 10 that rural-urban equality in access to electricity would still have the same reducing effect on ecological footprint of consumption without the influence of political stability. The coefficients of the interactions between the rural-urban energy equality measures and regulatory quality, and government effectiveness are statistically insignificant, suggesting that rural-urban energy equality would not be capable of lessening the ecological footprint of consumption in the presence of regulatory quality and government effectiveness. The coefficients of the interactions between the measures of rural-urban energy equality and rule of law are negative but statistically significant for the interaction between rural-urban equality in access to electricity and rule of law. While we find that rural-urban equality in access to electricity lowers ecological footprint in the presence of rule of law, we discover that rural-urban equality in access to electricity becomes less effective in reducing ecological footprint of consumption in the presence of rule of law relative to when rule of law is absent. The interactions between the rural-urban energy equality measures and voice and accountability have negative and statistically significant coefficients. This finding portends that higher rural-urban energy equality mitigates ecological footprint of consumption in the presence of voice and accountability. However, rural-urban energy equality has a greater mitigating effect in the absence of voice and accountability. Also, the coefficient on interaction between control of corruption and rural-urban equality in access to cooking fuels and technologies on ecological footprint of consumption is positive and statistically insignificant [see Model 11]. However, in Model 12, the coefficient of the interaction between rural-urban equality in access to electricity and control of corruption on ecological footprint of consumption is negative and statistically significant at 5% level and this suggests that increase in rural-urban equality in access to electricity reduces on ecological footprint of consumption in the presence of control of corruption. Overall, the marginal effect results demonstrate that the governance variables improve the effectiveness of rural-urban energy equality in reducing ecological footprint of consumption significantly.

4.3. Discussions

We pioneer the literature on the rural-urban energy equality-environment nexus by examining the effects of rural-urban energy equality as measured with rural-urban equality in access to cooking fuels and technologies and electricity on environmental sustainability (captured by total greenhouse gas emissions, ecological footprint of production, and ecological footprint of consumption) in SSA. Our study extends existing literature with fresh evidence in threefold. First, it establishes the effect of rural-urban energy equality on environmental sustainability using varied indicators of rural-urban energy equality and environmental sustainability. Second, it unfolds the role of the quality of governance in environmental sustainability from different aspects of governance. Finally, it demonstrates how governance moderates the environmental sustainability-effect of rural-urban energy equality.

First, we find that increase in rural-urban energy equality as measured with rural-urban equality in access to cooking fuels and technologies and electricity is associated with a reduction in greenhouse gas emissions, ecological footprint of production, and ecological footprint of consumption. This suggests that rural-urban energy equality could be pivotal in achieving environmental sustainability. Literature is replete with evidence of how increased energy consumption, particularly non-renewable energy, is inimical to environmental sustainability (Ahmad et al., 2016; Le et al., 2020; Wu et al., 2020). We are of opinion that this evidence may be driven by energy not being fairly distributed between the rural and urban areas. This unfair distribution gives rise to an unequal access to energy by the rural population relative to the urban population; hence, people living in rural areas would consume lesser energy than those in the urban areas. Our findings suggest that reducing the inequality in the access to energy between the rural and urban population creates a more sustainable environment. Drawing from the theory of distributive justice by John Rawl, we contend that ensuring a fair distribution of energy among all bridges the gap between the rural and urban population in access in energy and this resultantly allows the rural population to contribute favourably to the environmental sustainability drive. The rural population often lacks access to clean and modern energy; hence, some rely on the traditional (fossil fuel) sources to create energy, and this creates an obstacle for environmental sustainability. An interesting finding worth discussing is that rural-urban equality in access to clean cooking fuels and technologies is largely more influential than rural-urban equality in access to electricity in promoting environmental sustainability. This finding is not surprising. This is because clean cooking fuels and technologies are more environmental-friendly than electricity, which is mostly generated from non-renewable energy sources. Thus, we put forward that using rural-urban energy equality to achieve environmental sustainability would be more effective through reducing the inequality between the rural and urban population in the access to clean cooking fuels and technologies.

Second, we find that improved quality of governance through increased political stability and rule of law can foster environmental sustainability. Abid (2016) argues that a more stable political environment leads to a sustainable environment. Interestingly, we also find that governance tends to lower environmental sustainability when regulatory quality, voice and accountability, and government effectiveness become stronger. This finding is consistent with Halkos and Tzeremes (2013), who have noted that stronger governance does not necessarily support environmental sustainability. Thus, we argue that the capacity to achieve environmental sustainability via governance depends on the governance aspects. Also, our findings highlight that the measure of environmental sustainability is a factor to consider in understanding the role of governance in environmental sustainability. In our study, we recognize political stability as the most effective governance facet to achieve environmental sustainability.

Third, we generally observe that governance moderates the effect of the rural-urban energy equality variables to improve environmental sustainability. This evidence indicates that rural-urban energy equality promotes environmental sustainability in the presence of governance. While the literature has shown that SSA suffers from relatively less strong governance (institutional) quality (Acemoglu et al., 2003; Acemoglu, Johnson, & Robinson, 2001; Acheampong, Dzator, & Savage, 2021a), our analysis shows that with improvement in governance quality, rural-urban energy equality could contribute to environmental sustainability. We argue that weak governance is likely to make it difficult to close the gap between the rural and urban population in the access to energy. As a result, achieving rural-urban energy equality becomes less feasible and ultimately environmental sustainability. Rural-urban energy equality can only be attainable within a sound governance environment (Opoku & Acheampong, 2023). Buizer et al. (2014) argue that sound governance is crucial for issues bordering on the environment. Thus, promoting the role of rural-urban energy equality in ensuring environmental sustainability may not thrive in a weak governance environment. As far as our study reveals, it informs us that governance plays a significant role in conditioning rural-urban energy equality to enhance environmental sustainability.

5. Conclusion and policy implications

In this study, we contribute to the literature by investigating the impact of rural-urban energy equality on environmental degradation and the role that governance plays in such an effect. All the factors considered are policy driven. To start with, environmental issues and the consequential climate change are the direst challenges of this century, and many policy measures have been put in place to mitigate both their causes and impacts. Instrumental among these is the United Nations Sustainable Development Goals that has become the most monumental global developmental policy of our time. At the core of the sustainability agenda is the policy adoption to transition to a modern and sustainable energy (Goal 7) accessible by all to reduce emissions and be climate friendly (Goal 13). This is not surprising as at the 2023 climate change conference (COP28) the governments of almost 200 countries agreed for the first time to transition from fossil fuels.

Despite the push for universal access to modern energy, some rural folks especially in sub-Saharan Africa are largely left to rely on the natural environment to meet their energy needs and in the end exacerbating emissions, deforestation and the associated health implications. The inadequate modern energy in the rural areas relative to the urban has been as a result of rural-urban disparity in infrastructure provision. As estiblaished in the paper the provision of electricity, especially in sub-Saharan Africa, is a matter of policy and political will. A lack or inadequate provision of it calls into question the policy direction of countries and the effectiveness of governance. The Food and Agricultural Organization estimates that about 2.6 billion people globally use forest resources and other biomass to meet their energy demands. These people are mostly in the rural areas. Hence, for policymakers to reduce their environmental/carbon footprint, a plicy to provide adequate energy infrastructure in these areas meets a clarion call.

To provide some empirical basis for the call to policy to enhance rural electricification we used panel data for 47 sub-Saharan African countries between 2000 and 2020. Total greenhouse gas emissions, the ecological footprint of consumption, and the ecological footprint of production were used to measure environmental degradation. We represented the rural-urban energy equality variable with two proxies: (i) the ratio of rural to urban access to clean cooking fuels and technologies and (ii) the ratio of rural to urban access to electricity. The results revealed that the attainment of rural-urban access to energy equality could mitigate environmental degradation. We also documented through moderation and marginal effect analyses that governance reinforces rural-urban access to energy equality to reduce environmental degradation. These findings suggest that environmental degradation could be reduced by ensuring equity/equality in energy access between rural and urban population and a better governance system. All mentioned factors being policy relevant.

The study has enormous policy implications considering the Sustainable Development Goals, governments' developmental and environmental goals. Our study suggests that energy access equality principles should be integrated into formulating policies that address environmental degradation. The evidence from this study shows that rural-urban energy equality is important in driving environmental sustainability in sub-Saharan. Therefore, it is highly relevant for policymakers to address the energy access gap between rural and urban population. We suggest that bridging the energy access gap requires governments to be committed to implementing rural electrification and clean cooking technologies programs. Also, governments should support and incentivize the development of off-grid solutions. Off-grid solutions are important for addressing the rural-urban divide in energy access since national grid extension to rural areas could be more costly. Our findings also show that environmental sustainability can be achieved with good governance systems. In addition, a good governance system can support energy access equality to further address environmental degradation.

Although this paper makes a substantial contribution to the literature, there is still an avenue for future research. First, while we considered rural-urban energy equality at the macro level, future studies can focus on the micro to examine how access to electricity by rural folks can reduce their environmental footprint. Also, future studies can examine the pathways through which energy equality affects the environment.

Appendix A

Appendix Table 1A: List of countries.

Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African RepublicChad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, The, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, MadagascarMalawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

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