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Research paper

Electricity access, human development index, governance and income inequality in Sub-Saharan Africa

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ABSTRACT

Consistent with the Sustainable Development Goal 7 of ensuring access to clean and modern energy technologies, this study examined the nexus between access to electricity, human development index, political system environment, income level, and income inequality. We employed a nonparametric regression technique with Driscoll–Kraay standard errors from 1990 to 2017 in Sub-Saharan Africa. The study revealed that income inequality has a negative effect on access to electricity whereas income level and human development have a positive impact on access to electricity. Enhancing the political system environment in Sub-Saharan Africa is crucial to ensuring access to clean and modern electricity. The negative effect of political system on income inequality means that good governance environment reduces income inequality. Income inequality is found to reduce human development, as such, social protection policies that reduce poverty are essential to minimize the vulnerability to poverty. The study highlights that the effective promotion of labor markets and the improvement of socio-economic capacity to manage unemployment, infirmity, and disability will decrease income inequality, hence, promote human development.

1. Introduction

Access to modern energy services is essential to achieving basic social needs by promoting economic development. Modern energy services, particularly, electricity and gas have an effect on productivity, health, education, safe water and communication services (International Energy Agency, 2014). Energy per capita and electricity consumption are highly correlated with economic development and other indicators of modern lifestyle, with the presumption that electricity consumption is related to a better life and wellbeing (Starr, 1972). It is reported that the essentiality of energy, as well as the emphasis on energy accessibility, is the main driver of economic growth, poverty reduction, and reduction of income inequality (Poloamina and Umoh, 2013). Many studies have examined how access to energy affects economic growth (Adams et al., 2018; Shahbaz et al., 2013), but not much empirical research has been conducted to validate the other benefits in terms of poverty reduction and income inequality (Kanagawa and Nakata, 2008).

From a policy perspective, it is always important to ascertain those who benefits or loses from the improvements in energy access. This is consistent with the energy justice literature, which calls for the distribution of benefits and detriments of energy services across all members of society regardless of income, location, and race. Accordingly, this study aims at examining the case for Sub-Saharan Africa on the effect of access to electricity on income distribution. We make a case with individual and interaction effect of income inequality, political system and income level on access to electricity. We develop six conceptual tools essential for policy formulation in developing countries. A discussion of the distributional impact of electricity is important because inequality is considered as a socially corrosive threat to societal well-being (Wilkinson et al., 2010). The distributional effect of electricity is of great political interest and has featured in many public discussions around the world due to the growing social dissimilarities (Sen, 1997; Stiglitz et al., 2009). Equality, like fairness, is an important value in most societies, which can be a signal of lack of income mobility and opportunity (Dabla-Norris et al., 2015). This study is important because, in 2013, an estimated 1.2 billion people — representing 17% of the global population lacked access to electricity, 84 million less than in the previous year and more than 2.7 billion people — 38% of the world's population (mostly in Asia and Sub-Saharan Africa) — were projected to have relied on the traditional use of solid biomass for heating and cooking purposes (International Energy Agency, 2014).

The findings of previous studies (Estache, 2008; Heffron and McCauley, 2014; Sovacool and Dworkin, 2015) are consistent

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with the view that energy justice is impossible without government intervention. As noted by the Energy Justice Network, energy justice is not only necessary and possible but also affordable if there is a political will. Similarly, energy justice failures require more political commitment than just technical design. Accordingly, we control for the political economy dynamics in the nexus between electricity access and income distribution. Research indicates that achieving energy justice is still a challenge in developing countries because of the high perception of corruption — a fiber of poor governance (Estache, 2008). In a related study, government ineffectiveness appears to hinder electricity access in many developing countries (Poloamina and Umoh, 2013). To deal with this problem, we include a variable that accounts for corruption perception to reduce omitted variable bias in the model estimation.

To achieve this objective, we rely on a panel data framework that is robust to cross-sectional dependence, and unevenly spaced data series. We employ data comprising of 46 countries in Sub-Saharan Africa over the period 1990–2017. Our study is motivated by the limited quantitative evidence of the impact of electricity on economic development (especially in comparison to other publicly provided services). This study is timely and requires stronger evidence for better-informed policy decisions, such as the priorities of the public investment options (World Bank, 2015).

The remainder of the study proceeds as follows: Section 2 presents a review of the existing literature; Section 3 discusses the materials and method used; Sections 4 and 5 present findings and conclusion respectively.

2. Literature review

Access to modern energy is considered as a precondition for sustainable development, eradication of poverty and inequality, and consequently the realization of the Sustainable Development Goals (Kanagawa and Nakata, 2007, 2008; Ouedraogo, 2013a). According to the International Energy Agency (2014), inadequate access and availability of electricity aggravate poverty, inequality and hampers government revenues. Access to modern energy technologies is expansive (International Energy Agency, 2014; Kanagawa and Nakata, 2008; Martinez and Ebenhack, 2008; Niu et al., 2013, 2016), hence, a study on the socio-economic impact of inadequate electricity concluded that the poor and rural dwellers in developing countries stand to lose the most (Kanagawa and Nakata, 2007). Electricity extends working hours enabling economic agents to earn extra income and creates more job opportunities (IEA, 2016). Energy provides several social, informational and health benefits, thus, electricity forms the bedrock for satisfying the fundamental human needs (Niu et al., 2016).

The potential impact of energy or electricity access on inequality, human development and the quality of life has attracted several empirical studies. It is reported that electricity consumption correlates positively with human development index and GDP for 120 countries (Kanagawa and Nakata, 2008). The study found that countries with higher levels of electricity consumption rank high in economic activities and human development index. In a panel of countries, it is reported that electricity consumption improves human development (Niu et al., 2013) and is crucial for improving the well-being of people in developing countries (Mazur, 2011). Electricity consumption is essential to meet the basic human needs, and once these are satisfied, increasing electricity consumption in developed countries fails to generate the corresponding increase in the quality of life (Niu et al., 2016). Using correlation analysis, a strong relationship between human development index and energy consumption was found in 120 countries (Martinez and Ebenhack, 2008). The study concluded that a slight increase in energy access is associated with improvement in human development for poor countries. Economic crisis and a rise in electricity prices are reported to have harmful welfare consequences among the lower-income group (Romero-Jordán et al., 2016). Though electricity consumption is generally good for both the poor and the rich, however, an increase in electricity prices affects the livelihood of the poor compared to the rich. It is argued that energy poverty based on inadequate access to modern energy services is a direct consequence of income poverty (Balachandra, 2011). The inability of the poor to pay for energy services exacerbates poverty situations and widens the inequality gap between the poor and the rich. In a panel of 15 developing countries, it is reported that energy prices spur human development index but electricity consumption has no short term impact on human development index (Ouedraogo, 2013b). However, in the long term, electricity consumption is found to positively impact human development index.

There exist a handful of studies that consider the impact of electricity consumption on poverty, inequality, quality of life or human development index. The few studies reviewed largely point to the view that electricity access is good for the poor. However, the effect of political economy on the nexus between energy consumption and human development index has not been investigated. In developing countries, the government plays a major role in building and pricing energy infrastructure (Van Beers and Strand, 2013), hence, the distribution and access to electricity are more often a political decision. Energy policy, therefore, remains a net political gain rather than efficiency and economic rationality (Adams et al., 2016). This is the case in developing countries where the government largely subsidizes the prices of energy. In sub-Saharan Africa, issues of energy are key agenda on political manifestos and campaigns. Politicians promise to reduce energy prices and to extend electrification, especially in rural areas. As a result, government inefficiencies extend to the energy sector especially as leadership appointments in the sector are done by the government.

It is argued that energy has become political due to the increasing demand (influenced by economic growth) for energy, especially in emerging economies (Hughes and Lipscy, 2013). This results in an increased cost that encourages the government to subsidize the price in order to improve accessibility and affordability especially to the poor. In this paper, we examine the impact of electricity access, human development index and political system environment on income inequality. We further examine whether governance environment moderates the electricity access — income inequality relationship.

3. Materials & method

3.1. Data

Access to energy plays a critical role in the achievement of the Sustainable Development Goals 1 and 7. It is argued that human, social and economic development depend on the access to clean, modern and affordable energy technologies, especially in developing countries to help mitigate multidimensional poverty (Owusu and Asumadu, 2016). Based on the United Nations report on Sustainable Development Indicators (DiSano, 2002), the study used five data series from 1990–2017 presented in Table 1 — to empirically examine the role of income inequality on electricity access and vice versa. The data series include access to electricity, GDP per capita from the World Development Indicators (World Bank, 2018); Political system or governance environment from the quality of Government Institute Standard Dataset (Teorell et al., 2020); Human Development Index (HDI) from the United Nations Development Program dataset (UNDP, 2016), and

Table 1
Variable description.

Variable	Description	Unit
ACCESS	Access to electricity (% of the population)	%
PCGDP	GDP per capita	current US$
POLSYS	Political system or governance environment	Simple averages
HDI	Human Development Index (HDI) value	Score
GINI_DIS	GINI Disposable (Net)	Index

GINI Disposable (Net) from the standardized world income inequality database (Solt, 2016). Due to data availability, forward missing data series are forecasted with Microsoft Excel forecast technique with 99.99% confidence interval. However, backward missing data series are ignored to adopt an econometric technique capable of handling missing data. The study is examined in 46 countries in Sub-Saharan Africa (SSA) namely: Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Eswatini, Tanzania, The Gambia, Togo, Uganda, Zambia and Zimbabwe.

3.2. Data variable definition

Access to electricity is defined as the percentage of the population with access to electricity collated from national, industry surveys and renowned international databases (World Bank, 2018). GDP per capita is the summation of gross value added by the entire domestic producers in the economy plus any product taxes, minus any subsidies not included in the value of the products and excluding depreciation of fabricated assets or for depletion and degradation of natural resources divided by midyear population (World Bank, 2018). HDI is a "composite index measuring average achievement in three basic dimensions of human development along and healthy life, knowledge and a decent standard of living". HDI is based on a calculated score where 1 denotes Highest Human Development and 0 denotes Lowest Human Development (UNDP, 2016). Political institutional environment is an indicator measured from a combination of freedom of the press: political environment, freedom in the world: political rights, institutionalized democracy — institutionalized autocracy, checks and balances, democratic accountability, corruption, bureaucratic quality, internal conflict, military in politics, control of corruption, corruption perceptions index, and political terror scale (Kunčič, 2014). This variable measures the transparency of the political system in recognizing the needs of different groups of people and more importantly, how they participate in the decisions concerning the supply of energy. This helps to capture the three concepts (distribution, procedural, and recognition) espoused as key components of the energy justice framework (Heffron and McCauley, 2014; Sovacool and Dworkin, 2015). GINI Disposable (Net) estimates inequality in household post-tax and post-transfer income (Solt, 2016).

3.3. Estimation framework

The hypotheses of the study are presented as:

- Model 1: The nexus between access to electricity, income inequality, income level, and the interaction between income inequality and income level.
- Model 2: The nexus between access to electricity, human development index, political system environment and the interaction between the political system and human development index.
- Model 3: The relationship between access to electricity, human development index, political system environment, income level, and income inequality.
- Model 4: The relationship between income inequality, access to electricity, political system environment and the interaction between access to electricity and political system environment.
- Model 5: The relationship between income level, access to electricity, political system environment and the interaction between access to electricity and political system environment.
- Model 6: The relationship between human development index, income inequality, access to electricity, political system environment, the interaction between access to electricity and political system environment, the interaction between income inequality and political system environment, and the interaction between access to electricity, political system environment, and income inequality.

The hypotheses can be presented as a linear relationship expressed in Eqs. (1)–(6):

$$ACCESS = f(GINI_{DIS}, PCGDP, GINI_{DIS} * PCGDP) \quad (1)$$

$$ACCESS = f(HDI, POLSYS, POLSYS * HDI) \quad (2)$$

$$ACCESS = f(HDI, POLSYS, PCGDP, GINI_{DIS}) \quad (3)$$

$$GINI_{DIS} = f(ACCESS, POLSYS, ACCESS * POLSYS) \quad (4)$$

$$PCGDP = f(ACCESS, POLSYS, ACCESS * POLSYS) \quad (5)$$

$$HDI = f(GINI_{DIS}, ACCESS, POLSYS, ACCESS * POLSYS, GINI_{DIS} * POLSYS, ACCESS * POLSYS * GINI_{DIS}) \quad (6)$$

The specification of Eqs. (1), (3)–(5) follows a baseline econometric model expressed as:

$$ln\,(y)_{i,t} = ln(x)_{i,t}\beta + \epsilon_{i,t}, i = 1, \ldots, N, t = 1, \ldots, T. \quad (7)$$

And the specification of Eqs. (2) and (6) follow the estimation model expressed as:

$$ln(y)_{i,t} = \alpha_i + ln(x)_{i,t}\beta + \epsilon_{i,t}, i = 1, \ldots, N, t = 1, \ldots, T. \quad (8)$$

where $ln(y)$ represents the logarithmic transformation of the dependent variables $(ACCESS\,|GINI_{DIS}|\,PCGDP|HDI)$, α_i denotes the country fixed effects, $ln(x)$ represents the independent variables, β denotes the coefficient estimate, ϵ is the error term, i represents the cross-sectional units and t is the period.

Cross-sectional dependence is a challenge in panel data series where the cross-sectional units (i) are not sampled randomly, as such may depend on observable and unobservable common disturbances (Driscoll and Kraay, 1998). Standard estimation techniques fail to yield consistent estimates of the standard errors. Thus, following the work of Sarkodie and Strezov (2019), this study avoids the challenges associated with misspecification in traditional parametric estimation techniques and employs Driscoll and Kraay (1998) estimation technique based on nonparametric time series covariance matrix estimator which assumes that the error structure is heteroskedastic, autocorrelated up to some lag and perhaps correlated between the panels. Significantly, Driscoll–Kraay nonparametric estimator produces robust results in both cross-sectional and temporal dependence forms. It is capable of handling missing data series, a case in this study, and works in both balanced and unbalanced panels.

For brevity, the error structure in Eqs. (7)–(8) is modified to have a contemporaneous and lagged cross-sectional via a factor structure expressed as (Driscoll and Kraay, 1998):

$$\epsilon_{i,t} = \lambda_i f_t + \upsilon_{i,t} \quad (9)$$

$$\text{where } f_t = \rho f_{t-1} + u_{i,t} \quad (10)$$

$\upsilon_{i,t}$ and $u_{i,t}$ denote the forcing terms with zero mean. The forcing terms are uncorrelated mutually independent variables over time and across units. Cross-sectional dependence in the error structure occurs in the presence of an unobserved factor f_t common across units.

4. Results & Discussion

4.1. Descriptive statistics

This section presents the empirical results of the estimated models beginning with a descriptive statistical analysis to ascertain the characteristics of the data series. The descriptive statistical analysis of the data series is graphically presented in Fig. 1. Fig. 1 reveals that an average of 30.8% of the population in SSA has access to electricity. The political system environment and human development index in SSA averages below 0.50. The Gini disposable index reveals an average of 44.7% deviation from a perfectly equal distribution in SSA. Thus, on average, it appears that the distribution of income between the rich and the poor is not wide compared to other continents. However, the average per capita GDP is pegged at US$ 1538.31, meaning that SSA is above the poverty line (US$1.08) [(1538.31/365days = US$4.21/day)], which confirms the work of Sarkodie (2018) in Africa. The Jarque–Bera test statistic reveals that the data series do not exhibit a normal distribution, hence, justifying the application of logarithmic transformation prior to model estimation to provide the data series with a constant variance. The boxplot reveals that a high majority of per capita GDP in SSA is concentrated below US$ 2000 while the Gini disposable index is concentrated between 38%–48%. The percentage of the population with access to electricity in SSA is concentrated below 25%. The human development index in SSA is concentrated between 0.35–0.55. In accordance with the ranking by UNDP (2016), Mauritius and Seychelles are the only countries in SSA with a High Human Development Index. On the contrary, South Africa, Botswana, Gabon, Cape Verde, Namibia, Congo, Ghana, Equatorial Guinea, Zambia and São Tomé and Principe are in the Medium Human Development Index category while the remaining countries are in the Low Human Development Index category. The distribution plot reveals that the political system environment is concentrated between 0.25–0.40, signifying a poor political environment in SSA.

4.2. Panel unit root test

En route to the model estimation, the study performed a variety of tests for stationarity in the panel data series. Table 2 presents the results of panel unit root tests namely Breitung, Levin–Lin–Chu (LLC), Hadri Lagrange Multiplier and Pesaran's cross-sectionally augmented Dickey–Fuller (CADF) test.

Breitung (1999) and LLC Levin et al. (2002) panel unit root tests are estimated based on the null hypothesis that the panels contain a unit root while Hadri is based on the null hypothesis that all panels are stationary. CADF is a second-generation panel unit root test which runs a t-test statistic in the presence of cross-sectional dependence based on a null hypothesis that all series are nonstationary (Pesaran et al., 2003). Results from Table 2 reveal that the data series in the panel have a unit root at level but turns stationary at first difference, hence, integrated of order one.

4.3. Access model with interaction between income inequality and income level

This section presents the empirical results of the nexus between access to electricity, income inequality, income level, and the interaction between income inequality and income level reported in Table 3 row 1–5. The estimated coefficient of income inequality is negative and statistically significant at 1% level, hence, reject the null hypothesis that the estimated coefficient on income inequality is equal to zero. On the contrary, the estimated coefficient of income level is positive and statistically significant at 1% level. However, the interaction between income inequality and income level is negative and significant at 1% level. Quantitatively, the coefficients of income inequality, income level, and the interaction between income inequality and income level are approximately −0.69%, 1.53% and −0.18%, respectively, at a predictive power of 90% in 45 countries using Driscoll and Kraay (1998) pooled OLS.

According to the Sustainable Development Goal (SDG) 7, access to affordable and modern energy is crucial to human development, due to its role in poverty eradication (United Nations, 2015). However, our study reveals that inequality in the distribution of income among households within the economy in SSA countries decreases access to electricity. Meaning that as the ratio of the share of national income between the highest 20% of SSA population to the lowest 20% of the SSA population widens, inequality in socio-economic, health and welfare opportunities increases, hence, affect human development and hamper long-term economic development (DiSano, 2002; Owusu and Asumadu, 2016). Increasing income inequality in SSA further affects the choice of energy technologies. Poor people generally have less income and less access to services, as such, unable to pay for cleaner and modern energy technologies. They turn to rely on cheap, vintage and pollution-intensive energy technologies such as solid fuel (firewood and charcoal) and kerosene for cooking and heating purposes, which eventually affect environmental sustainability and quality of life. IEA (2017) reveals that 90% of households in SSA rely on charcoal, fuelwood, and waste for cooking and heating purposes, which results in creating noxious fumes leading to premature deaths. According to the United Nations Sustainable Development Indicators (DiSano, 2002), the share of the population that employs solid fuels is a proxy for indoor air pollution. Indoor air pollution which is associated with high mortality rates from pneumonia, other acute lower respiratory infections among children, lung cancer, and chronic obstructive pulmonary diseases. On the contrary, when income levels become equitable in SSA, poverty is alleviated while socio-economic, health and human development opportunities increases, hence, causing the poor to benefit from a double dividend leading to sustainable development. Evidence from the study shows that increasing income level in SSA increases access to electricity. As income level increases in developing countries, the willingness to pay for clean and modern electricity supply increases, thus, improving the quality of life and human development. Sarkodie and Adom (2018) revealed that higher income levels increase the scale effect in Africa rather than the technique effect, as such, increases energy consumption due to the accessibility to energy supplies. The negative effect of the interaction between income inequality and income level on access to electricity suggest that income inequality reduces access to electricity when the initial income level is lower in SSA countries.

The country-specific access model with interaction between income inequality and income level and Income inequality model presented in Table 5 produces mixed results. The effect of income inequality on access to electricity is positive and statistically significant in Angola, Benin, Cape Verde, Cameroon, Chad, Comoros, Congo, Côte d'Ivoire, Ghana, Guinea, Kenya, Madagascar,

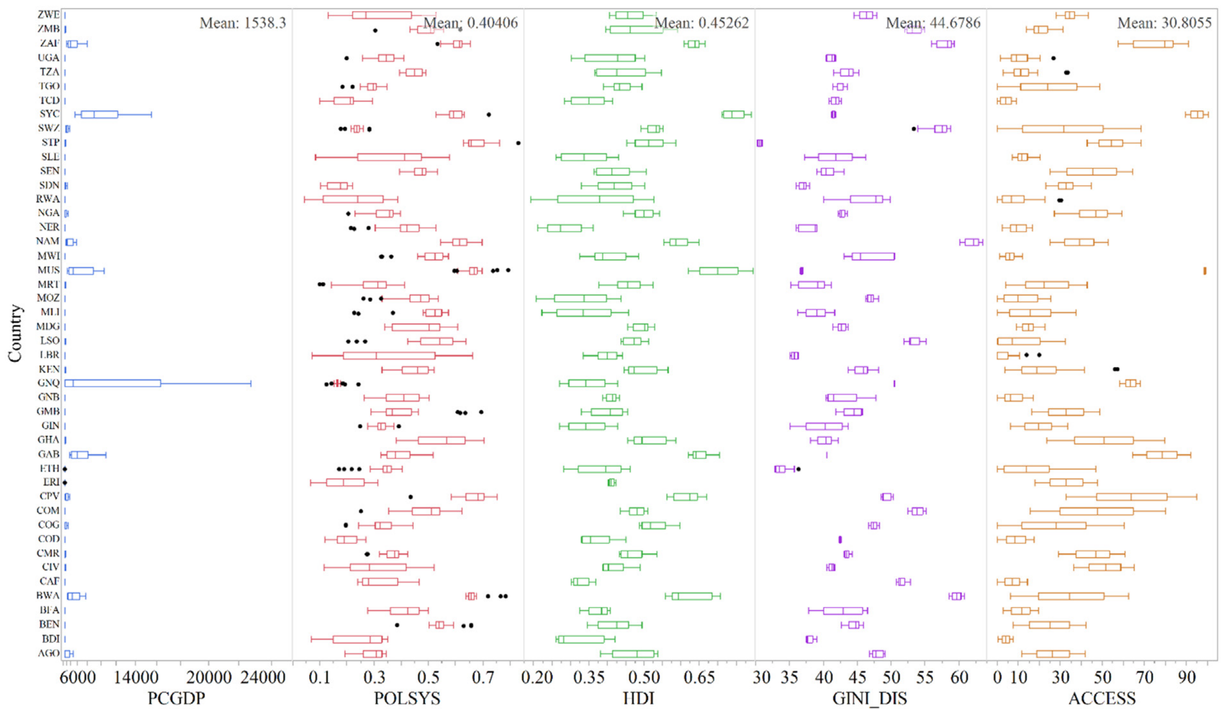

Fig. 1. Descriptive Statistics of the data series across countries. Note: Countries are presented based on ISO 3166-1 alpha-3 codes.

Table 2
Panel unit root tests.

Variable	Breitung		LLC		Hadri		CADF	
	Level	1st Diff	Level	1st Diff	Level	1st Diff	Level	1st Diff
ACCESS	16.04	−23.97	1.21	−22.06	110.26	−4.02	−1.77	−2.74
Prob	1.00	0.00***	0.89	0.00***	0.00***	1.00	0.47	0.00***
PCGDP	5.48	−14.08	5.67	−12.10	91.81	0.94	−1.56	−1.99
Prob	1.00	0.00***	1.00	0.00***	0.00***	1.00	0.92	0.06*
POLSYS	0.78	−11.83	−19.64	−7.18	74.44	−2.83	−1.90	−2.28
Prob	0.78	0.00***	0.00***	0.00***	0.00***	1.00	0.16	0.00***
HDI	17.00	−10.70	2.00	−6.84	97.59	−3.00	1.41	−5.62
Prob	1.00	0.00***	0.98	0.00***	0.00***	1.00	0.92	0.00***
GINI_DIS	9.74	−9.69	3.02	−540.00	71.60	−0.42	−1.94	−2.38
Prob	1.00	0.00***	1.00	0.00***	0.00***	0.66	0.11	0.00***

Note: *,**,*** denote statistical significance at 1, 5 and 10% levels.

Malawi, Mauritania, Mauritius, Namibia, Nigeria, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Eswatini, Tanzania, The Gambia, and Zimbabwe. However, the impact of income inequality on access to electricity is negative and statistically significant in Central African Republic, Dem. Rep. Congo, Ethiopia, Liberia, Mozambique, and Uganda.

Again, the relationship between income level and access to electricity is positive in Angola, Burkina Faso, Burundi, Cape Verde, Central African Republic, Comoros, Ethiopia, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Namibia, Niger, Nigeria, São Tomé and Principe, Senegal, Sierra Leone, Sudan, The Gambia, and Zimbabwe. But the relationship is negative and significant in Benin, Botswana, Cameroon, Chad, Congo, Côte d'Ivoire, Ghana, Mozambique, Rwanda, South Africa, Eswatini, Tanzania, Togo, and Uganda.

The impact of the interaction between income inequality and income level on access to electricity reveals a positive effect in Benin, Botswana, Cameroon, Chad, Congo, Côte d'Ivoire, Ghana, Rwanda, South Africa, Eswatini, Tanzania, Togo, and Uganda. Meaning that income levels improve income distribution in households, hence, increases access to electricity. Nevertheless, the nexus between interaction between income inequality and income level on access to electricity reveals a negative effect in Angola, Burkina Faso, Burundi, Cape Verde, Central African Republic, Comoros, Ethiopia, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mauritania, Mauritius, Namibia, Niger, Nigeria, São Tomé and Principe, Senegal, Sierra Leone, The Gambia, and Zimbabwe. The results mean that high-income levels make the rich richer and the poor poorer, thus, increasing inequality in income distribution and eventually reducing access to electricity.

4.4. Access model with interaction between political system and human development index

The nexus between access to electricity, human development index, political system environment and the interaction between political system and human development index were examined using Driscoll and Kraay (1998) regression by accounting for country fixed effects. The outcome of the study is presented in Table 5 rows 6–11. The estimated coefficients of human development index, political system environment and the interaction between political system environment and human development index are positive and statistically significant at 1% level. This infers that improvement in the average achievement in three basic dimensions of human development namely; a decent standard of living (gross national income and household income levels), healthy life (life expectancy and healthy living), and knowledge (education index) in SSA increases access to electricity (UNDP, 2016). For example, improvement in human development in SSA leads to a paradigm shift from the traditional use of biomass (fuelwood, charcoal, and waste) for cooking and heating purposes and drastically reduce the number of hours used by women and children to gather fuelwood. Thus, reduction of time used by women in gathering fuelwood for other economic activities like the involvement of women in cookstove supply chain will improve their economic standing (IEA, 2017). This will in effect promote clean cooking and reduce the risk of household air pollution-related to burning fuelwood, charcoal, and waste for cooking and heating purposes, thus, declining the number of premature deaths associated with indoor air pollution (IEA, 2017). Improvements in the political environment in SSA is critical to ensuring access to a clean and modern electricity supply. Government effort, in terms of energy sector infrastructure investment, development of localized energy technologies and long-term political commitment to energy policies will reduce financial and investment risk and provide an enabling environment that promotes access to electricity. Improving the political environment in SSA encompasses political feasibility (i.e. acceptance and support by stakeholders, constituencies, organizations and the compatibility with cultural norms and traditions), and administrative feasibility (i.e. compatibility with available indigenous information base, legal structure, administrative capacity and financial institutional capacity) leading to institutional feasibility (i.e. legitimacy of policy instrument, able to gain acceptance, able to be adopted and implemented) (Edenhofer et al., 2011). Sarkodie and Adams (2018) revealed that the quality of political institutions plays a crucial role in the economic, social and governance readiness to effect change (i.e. such as reforms, policies and adaptation options). The positive effect of the interaction between political system and human development index on access to electricity means that the combined effect of a good political environment and improved human development indicators will increase access to electricity in SSA.

4.5. Access to electricity model without interaction

The study corroborates the empirical estimation of the access model with interaction, by examining the relationship between access to electricity, human development index, political system environment, income level and income inequality without the inclusion of interaction effect in 45 countries. The coefficients of human development index and income level are positive and significant at 1% level, however, the coefficient on political system environment is positive but insignificant (Rows 12–18 in Table 5). On the contrary, the estimated coefficient on income inequality is negative and significant. Hence, the access to electricity model without interaction effect validates the outcome of the access models with an interaction effect. This implies that inequality in income distribution in SSA has a negative effect on access to electricity while improvements in income level and human development index have a positive impact on access to electricity.

4.6. Income inequality model

This section examines the relationship between income inequality, access to electricity, political system environment and the interaction between access to electricity and political system environment by incorporating country fixed effects in the Driscoll and Kraay (1998) OLS regression. The results of the income inequality model are presented in rows 1–5 in Table 4. The estimated coefficient on access to electricity is positive and statistically significant at 1% level. A positive effect means that access to electricity minimizes poverty due to economic productivity, however, inequality of income distribution widens. The other scenario is that accessibility to electricity does not mean affordability, as such, high electricity tariffs affect the population or households in the lowest 20% of national income bracket. In this regard, SDG 7 proposes affordable modern energy technologies which warrant sustainable economic and human development (United Nations, 2015). The negative effect of the political system environment on income inequality means that good governance environment reduces inequality of income distribution. In other to achieve a reduction in income inequality, SDG 10 (United Nations, 2015) proposes a governance environment that promotes equal opportunity via the elimination of discriminatory laws, policies, and practices while promoting legislation, policies, and actions that reduces income inequalities. A good governance environment in SSA ensures an improvement in financial regulations, monitors global financial markets and institutions and promotes the implementation of such financial regulations (United Nations, 2015). A positive impact of the interaction between access to electricity and political system environment on income inequality means that the initial effect of the governance environment increases income inequality. This could be explained by the weak or poor governance environment in many of the SSA countries. The country-specific results in Table 5 columns 6–9 produce the same outcome as the entire model except for Lesotho. Contrary to the results from other countries, access to electricity and governance environment reduce income inequality. In the same vein, the interaction between access to electricity and political system environment reduces income inequality in Lesotho.

Table 3
Access to electricity model.

Row	lnACCESS (Model 1)	Coef.	Std. Err.	P > t
1	lnGINI_DIS	−0.69	0.16	0.00
2	lnPCGDP	1.53	0.34	0.00
3	lnGINI_DIS*lnPCGDP	−0.18	0.07	0.01
4	Number of obs	1017	Number of groups	45
5	Prob > F	0.00	R-squared	0.90
	lnACCESS (Model 2)	Coef.	Std. Err.	P > t
6	lnHDI	4.57	0.62	0.00
7	lnPOLSYS	1.49	0.36	0.00
8	lnPOLSY*lnHDI	0.66	0.28	0.03
9	_cons	7.54	0.58	0.00
10	Number of obs	1148	Number of groups	46
11	Prob > F	0.00	within R-squared	0.28
	lnACCESS (Model 3)	Coef.	Std. Err.	P > t
12	lnHDI	1.16	0.34	0.00
13	lnPOLSYS	0.29	0.24	0.22
14	lnPCGDP	0.57	0.11	0.00
15	lnGINI_DIS	−2.15	0.79	0.01
16	_cons	8.55	2.26	0.00
17	Number of obs	965	Number of groups	45
18	Prob > F	0.00	R-squared	0.42

4.7. Income level model

The relationship between income level, access to electricity, governance environment and the interaction between access to electricity and governance environment is presented in rows 6–10 of Table 4. The estimated coefficient on access to electricity yields a positive effect significant at 1% level. Meaning that access to electricity improves economic development in SSA. Our study is in line with Kanagawa and Nakata (2008), who found a positive relationship between access to electricity and income level. They argue that access to electricity improves income through the creation of electrification jobs by enterprise development. Mechanization in industrial sectors due to the access

Table 4
Income inequality, Income level, and HDI model.

Row	lnGINI_DIS (Model 4)	Coef.	Std. Err.	P > t
1	lnACCESS	1.00	0.02	0.00
2	lnPOLSYS	−2.51	0.13	0.00
3	lnACCESS*lnPOLSYS	0.63	0.05	0.00
4	Number of obs	1017	Number of groups	45
5	Prob > F	0.00	R-squared	0.97
	lnPCGDP (Model 5)	Coef.	Std. Err.	P > t
6	lnACCESS	1.94	0.04	0.00
7	lnPOLSYS	−3.54	0.11	0.00
8	lnACCESS*lnPOLSYS	1.01	0.05	0.00
9	Number of obs	1288	Number of groups	46
10	Prob > F	0.00	R-squared	0.96
	lnHDI (Model 6)	Coef.	Std. Err.	P > t
11	lnGINI_DIS	−0.48	0.14	0.00
12	lnACCESS	0.07	0.02	0.00
13	lnPOLSYS	1.90	0.61	0.00
14	lnACCESS*lnPOLSYS	1.09	0.18	0.00
15	lnGINI_DIS*lnPOLSYS	−0.46	0.16	0.01
16	lnACCESS*lnPOLSYS*lnGINI_DIS	0.28	0.05	0.00
17	_cons	0.92	0.54	0.10
18	Number of obs	965	Number of groups	45
19	Prob > F	0.00	within R-squared	0.50

to electricity improves economic development. DiSano (2002) argues that access to electricity and other clean and modern energy services provide basic social services and reduces poverty while increasing economic development. Thus, availability, accessibility, affordability, and reliable electricity and other energy services are essential to warrant a sustainable economic and human development. The negative effect of governance environment on income levels reveals a weak governance environment that promotes unequal opportunity due to discriminatory laws, policies, and practices that reduces income levels. Weak policies on wage, fiscal and social protection hamper economic development and eventually affect household income levels. Thus, economic development in SSA requires an improved political system environment that ensures an enhancement in financial regulations. In this regard, SDG 8 proposes a decline in unemployment rates, increasing labor productivity, improving access to financial services, and strengthening the capacity of indigenous financial sectors (United Nations, 2015). The positive estimated coefficient on the interaction between access to electricity and political system environment means that the de facto effect of access to electricity positively impacts income levels even in the initial weak governance environment in SSA.

4.8. Human development index model

The section examines the nexus between human development index, income inequality, access to electricity, governance environment, the interaction between access to electricity and political system environment, the interaction between income inequality and political system environment, and the interaction between access to electricity, political system environment, and income inequality. This model considers the country-specific fixed effects examined in 45 countries, with corresponding results presented in rows 11–19 of Table 4. The estimated coefficients on income inequality and the interaction between income inequality and political system environment are negative and statistically significant at 1% level. This implies that inequality in the distribution of income in SSA negatively affects the three arms of human development index namely; a decent standard of living, long and healthy life and knowledge. The disparities in income affect the choices of the poor in all dimensions of life. For example, low-income levels affect the choice of healthy and nutritious food, access to modern energy technologies, sustainable agricultural practices, clean water and sanitation, quality education and among others. According to SDG 1, 42% of people in SSA continues to live in extreme multidimensional poverty (United Nations, 2015). Income inequality translates into the larger population in SSA which still depends on traditional biomass such as fuelwood, charcoal, and waste for cooking and heating purposes. According to IEA (2017), 90% of households in SSA lack access to clean and modern cooking but rely on solid biomass in traditional stoves, thus, translating into over billions of hours per annum utilized by women and children for collecting solid fuel. In this regard, equity in the distribution of income in SSA will improve quality of life and wellbeing by switching from pollution-intensive traditional energy to clean and modern energy technologies.

The negative effect of the interaction between income inequality and political system environment means that the initial strong effect of income disparity tilts human development to negative even in a conducive political system environment. According to UNDP (2016), economic development is the most important indicator of human development, even though other indicators like health and knowledge matters. Economic development, in the form of reducing income inequality, serves as the gateway to improving health and knowledge, hence, improving human development.

The coefficient on access to electricity, political system environment, the interaction between access to electricity and political system environment, and the interaction between access to electricity, political system environment, and income inequality is positive and significant at 1% level. Replacing pollution-intensive traditional solid biomass used for cooking and heating purposes in SSA with electricity reduces the time spent by woman and children in gathering fuelwood and eradicate noxious indoor air pollution associated with several health hazards. In the case where electricity supply is based on renewable and clean energy technologies, it may serve as a source of jobs and opportunities for less endowed people in SSA. Access to energy contributes to the eradication of poverty, and economic productivity while promoting human development.

Enhanced political system environment in SSA does not only create a conducive environment for small and medium scale enterprises to thrive, but provide policies that improve the socio-economic living standards of both the poor and the rich. UNDP (2016) argues that government initiative that provides renewable energy to the poor population would improve biodiversity where the livelihoods of poor people are centered, thus, reversing the downward spiral of poverty and environmental degradation.

The positive effect of the interaction between access to electricity and political system environment means that a combined effort that increases accessibility to affordable electricity and promotes good governance environment in SSA will enhance access to knowledge, promote long and healthy life while improving the standard of living. The interaction between income inequality and political system environment, and the interaction between access to electricity, political system environment, and income inequality reveals that a proportion of all the factors have a positive impact on human development.

Robustness — We examined the robustness by diagnosing the independence of the residuals of the six models using conditional marginal effects as a post-estimation technique. Figs. 2–7 depict the model verification with their corresponding 95% confidence interval (CI) represented in a red short-dash dot–dot. It is noticeable that all the plots using the Conditional Marginal Effects are within the 95% confidence interval, thus, confirming the robustness of the estimated models.

Table 5
Country-specific access model with interaction between income inequality and income level and Income inequality model.

Country	lnACCESS (Model 1)	Coef.	Drisc/Kraay Std. Err.	P > t	lnGINI_DIS (Model 4)	Coef.	Drisc/Kraay Std. Err.	P > t
Angola	lnGINI_DIS	0.63	0.14	0.00	lnACCESS	1.20	0.02	0.00
	lnPCGDP	3.31	1.65	0.06	lnPOLSYS	−3.57	0.17	0.00
	lnGINI_DIS*lnPCGDP	−0.82	0.44	0.08	lnACCESS*lnPOLSYS	1.11	0.06	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Benin	lnGINI_DIS	1.03	0.30	0.00	lnACCESS	1.14	0.01	0.00
	lnPCGDP	−4.70	1.00	0.00	lnPOLSYS	−5.51	0.06	0.00
	lnGINI_DIS*lnPCGDP	1.22	0.22	0.00	lnACCESS*lnPOLSYS	1.66	0.02	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Botswana	lnGINI_DIS	0.11	0.55	0.84	lnACCESS	1.73	0.11	0.00
	lnPCGDP	−19.45	5.97	0.00	lnPOLSYS	−9.64	0.34	0.00
	lnGINI_DIS*lnPCGDP	4.84	1.40	0.00	lnACCESS*lnPOLSYS	4.07	0.31	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Burkina Faso	lnGINI_DIS	0.12	0.35	0.73	lnACCESS	1.66	0.15	0.00
	lnPCGDP	2.40	0.64	0.00	lnPOLSYS	−4.53	0.35	0.00
	lnGINI_DIS*lnPCGDP	−0.55	0.23	0.02	lnACCESS*lnPOLSYS	2.03	0.28	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Burundi	lnGINI_DIS	−0.39	0.36	0.29	lnACCESS	2.30	0.19	0.00
	lnPCGDP	11.36	5.66	0.06	lnPOLSYS	−1.92	0.10	0.00
	lnGINI_DIS*lnPCGDP	−2.98	1.59	0.07	lnACCESS*lnPOLSYS	1.29	0.18	0.00
	R-squared	0.93	Prob > F	0.00	R-squared	0.99	Prob > F	0.00
Cape Verde	lnGINI_DIS	1.52	0.21	0.00	lnACCESS	0.96	0.01	0.00
	lnPCGDP	10.29	1.76	0.00	lnPOLSYS	−11.24	0.42	0.00
	lnGINI_DIS*lnPCGDP	−2.70	0.48	0.00	lnACCESS*lnPOLSYS	2.76	0.12	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Cameroon	lnGINI_DIS	0.70	0.13	0.00	lnACCESS	1.00	0.01	0.00
	lnPCGDP	−4.65	0.84	0.00	lnPOLSYS	−3.69	0.05	0.00
	lnGINI_DIS*lnPCGDP	1.28	0.21	0.00	lnACCESS*lnPOLSYS	0.99	0.02	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Central African Republic	lnGINI_DIS	−0.38	0.50	0.45	lnACCESS	2.54	0.31	0.00
	lnPCGDP	35.41	5.68	0.00	lnPOLSYS	−3.23	0.26	0.00
	lnGINI_DIS*lnPCGDP	−8.84	1.52	0.00	lnACCESS*lnPOLSYS	2.02	0.23	0.00
	R-squared	0.98	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Chad	lnGINI_DIS	0.24	0.07	0.00	lnACCESS	2.21	0.03	0.00
	lnPCGDP	−10.60	0.38	0.00	lnPOLSYS	−2.47	0.03	0.00
	lnGINI_DIS*lnPCGDP	2.88	0.10	0.00	lnACCESS*lnPOLSYS	1.46	0.03	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Comoros	lnGINI_DIS	0.80	0.08	0.00	lnACCESS	1.00	0.00	0.00
	lnPCGDP	5.90	0.13	0.00	lnPOLSYS	−7.56	0.13	0.00
	lnGINI_DIS*lnPCGDP	−1.44	0.04	0.00	lnACCESS*lnPOLSYS	1.89	0.03	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Congo	lnGINI_DIS	1.10	0.08	0.00	lnACCESS	1.05	0.03	0.00
	lnPCGDP	−9.11	0.46	0.00	lnPOLSYS	−3.15	0.03	0.00
	lnGINI_DIS*lnPCGDP	2.34	0.12	0.00	lnACCESS*lnPOLSYS	0.86	0.02	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Côte d'Ivoire	lnGINI_DIS	0.36	0.10	0.00	lnACCESS	0.95	0.03	0.00
	lnPCGDP	−4.88	1.01	0.00	lnPOLSYS	−2.87	0.69	0.00
	lnGINI_DIS*lnPCGDP	1.41	0.27	0.00	lnACCESS*lnPOLSYS	0.73	0.16	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Dem. Rep. Congo	lnGINI_DIS	−0.55	0.46	0.25	lnACCESS	1.28	0.09	0.00
	lnPCGDP	0.08	25.79	1.00	lnPOLSYS	−2.25	0.04	0.00
	lnGINI_DIS*lnPCGDP	0.19	6.95	0.98	lnACCESS*lnPOLSYS	0.76	0.08	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Ethiopia	lnGINI_DIS	−0.77	0.22	0.00	lnACCESS	1.25	0.07	0.00
	lnPCGDP	13.69	2.65	0.00	lnPOLSYS	−3.43	0.03	0.00
	lnGINI_DIS*lnPCGDP	−3.61	0.75	0.00	lnACCESS*lnPOLSYS	1.22	0.07	0.00
	R-squared	0.99	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Ghana	lnGINI_DIS	1.12	0.05	0.00	lnACCESS	0.85	0.03	0.00
	lnPCGDP	−6.51	0.55	0.00	lnPOLSYS	−3.30	0.64	0.00
	lnGINI_DIS*lnPCGDP	1.75	0.14	0.00	lnACCESS*lnPOLSYS	0.71	0.22	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Guinea	lnGINI_DIS	1.60	0.26	0.00	lnACCESS	1.23	0.04	0.00
	lnPCGDP	4.52	0.48	0.00	lnPOLSYS	−3.66	0.06	0.00
	lnGINI_DIS*lnPCGDP	−1.36	0.17	0.00	lnACCESS*lnPOLSYS	1.22	0.04	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Guinea-Bissau	lnGINI_DIS	−1.38	0.86	0.12	lnACCESS	1.56	0.17	0.00
	lnPCGDP	0.06	1.77	0.97	lnPOLSYS	−3.28	0.26	0.00
	lnGINI_DIS*lnPCGDP	0.30	0.35	0.39	lnACCESS*lnPOLSYS	1.33	0.30	0.00
	R-squared	0.96	Prob > F	0.00	R-squared	1.00	Prob > F	0.00

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Table 5 (*continued*).

Country	lnACCESS (Model 1)	Coef.	Drisc/Kraay Std. Err.	P > t	lnGINI_DIS (Model 4)	Coef.	Drisc/Kraay Std. Err.	P > t
Kenya	lnGINI_DIS	1.46	0.52	0.01	lnACCESS	1.25	0.06	0.00
	lnPCGDP	19.19	4.11	0.00	lnPOLSYS	−4.73	0.23	0.00
	lnGINI_DIS*lnPCGDP	−5.13	1.16	0.00	lnACCESS*lnPOLSYS	1.57	0.12	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Lesotho	lnGINI_DIS	0.75	1.17	0.53	lnACCESS	−0.50	0.24	0.05
	lnPCGDP	104.68	11.23	0.00	lnPOLSYS	−6.29	0.45	0.00
	lnGINI_DIS*lnPCGDP	−26.43	2.95	0.00	lnACCESS*lnPOLSYS	−1.07	0.27	0.00
	R-squared	0.94	Prob > F	0.00	R-squared	0.97	Prob > F	0.00
Liberia	lnGINI_DIS	−7.09	2.27	0.01	lnACCESS	0.69	0.22	0.01
	lnPCGDP	−11.15	19.47	0.58	lnPOLSYS	−4.70	0.19	0.00
	lnGINI_DIS*lnPCGDP	4.40	5.78	0.46	lnACCESS*lnPOLSYS	0.43	0.30	0.18
	R-squared	0.88	Prob > F	0.00	R-squared	0.99	Prob > F	0.00
Madagascar	lnGINI_DIS	0.85	0.21	0.00	lnACCESS	1.39	0.04	0.00
	lnPCGDP	8.66	1.71	0.00	lnPOLSYS	−4.90	0.43	0.00
	lnGINI_DIS*lnPCGDP	−2.33	0.49	0.00	lnACCESS*lnPOLSYS	1.80	0.13	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Malawi	lnGINI_DIS	0.75	0.34	0.04	lnACCESS	2.14	0.44	0.00
	lnPCGDP	6.77	1.74	0.00	lnPOLSYS	−4.24	0.45	0.00
	lnGINI_DIS*lnPCGDP	−1.82	0.51	0.00	lnACCESS*lnPOLSYS	2.48	0.79	0.00
	R-squared	0.97	Prob > F	0.00	R-squared	0.99	Prob > F	0.00
Mali	lnGINI_DIS	−0.86	1.07	0.43	lnACCESS	1.17	0.14	0.00
	lnPCGDP	5.54	2.97	0.08	lnPOLSYS	−5.43	0.17	0.00
	lnGINI_DIS*lnPCGDP	−1.26	0.96	0.20	lnACCESS*lnPOLSYS	1.74	0.24	0.00
	R-squared	0.98	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Mauritania	lnGINI_DIS	2.19	0.65	0.00	lnACCESS	0.88	0.17	0.00
	lnPCGDP	8.73	1.69	0.00	lnPOLSYS	−1.68	0.35	0.00
	lnGINI_DIS*lnPCGDP	−2.60	0.55	0.00	lnACCESS*lnPOLSYS	0.32	0.24	0.20
	R-squared	0.99	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Mauritius	lnGINI_DIS	1.29	0.00	0.00	lnACCESS	0.79	0.00	0.00
	lnPCGDP	0.46	0.09	0.00	lnPOLSYS	−1.65	2.16	0.45
	lnGINI_DIS*lnPCGDP	−0.13	0.02	0.00	lnACCESS*lnPOLSYS	0.36	0.47	0.45
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Mozambique	lnGINI_DIS	−2.06	0.46	0.00	lnACCESS	1.57	0.15	0.00
	lnPCGDP	−3.08	6.50	0.64	lnPOLSYS	−5.08	0.10	0.00
	lnGINI_DIS*lnPCGDP	1.25	1.68	0.46	lnACCESS*lnPOLSYS	2.11	0.24	0.00
	R-squared	0.99	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Namibia	lnGINI_DIS	0.92	0.12	0.00	lnACCESS	1.18	0.01	0.00
	lnPCGDP	5.84	0.83	0.00	lnPOLSYS	−9.66	0.21	0.00
	lnGINI_DIS*lnPCGDP	−1.42	0.21	0.00	lnACCESS*lnPOLSYS	2.74	0.05	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Niger	lnGINI_DIS	0.11	0.59	0.86	lnACCESS	1.84	0.02	0.00
	lnPCGDP	5.22	2.44	0.04	lnPOLSYS	−4.18	0.06	0.00
	lnGINI_DIS*lnPCGDP	−1.34	0.77	0.09	lnACCESS*lnPOLSYS	2.13	0.04	0.00
	R-squared	0.99	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Nigeria	lnGINI_DIS	0.79	0.04	0.00	lnACCESS	1.00	0.01	0.00
	lnPCGDP	4.35	1.26	0.00	lnPOLSYS	−3.55	0.09	0.00
	lnGINI_DIS*lnPCGDP	−1.12	0.34	0.00	lnACCESS*lnPOLSYS	0.95	0.03	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Rwanda	lnGINI_DIS	0.85	0.52	0.11	lnACCESS	1.41	0.14	0.00
	lnPCGDP	−20.73	2.34	0.00	lnPOLSYS	−1.59	0.12	0.00
	lnGINI_DIS*lnPCGDP	5.31	0.55	0.00	lnACCESS*lnPOLSYS	0.59	0.09	0.00
	R-squared	0.87	Prob > F	0.00	R-squared	0.98	Prob > F	0.00
São Tomé and Principe	lnGINI_DIS	1.10	0.07	0.00	lnACCESS	0.86	0.00	0.00
	lnPCGDP	4.01	0.90	0.00	lnPOLSYS	−8.79	0.12	0.00
	lnGINI_DIS*lnPCGDP	−1.16	0.27	0.00	lnACCESS*lnPOLSYS	2.21	0.03	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Senegal	lnGINI_DIS	1.16	0.24	0.00	lnACCESS	1.00	0.01	0.00
	lnPCGDP	6.23	0.57	0.00	lnPOLSYS	−5.35	0.09	0.00
	lnGINI_DIS*lnPCGDP	−1.70	0.19	0.00	lnACCESS*lnPOLSYS	1.45	0.03	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Seychelles	lnGINI_DIS	1.11	0.06	0.00	lnACCESS	0.82	0.00	0.00
	lnPCGDP	0.10	0.47	0.83	lnPOLSYS	−6.25	0.47	0.00
	lnGINI_DIS*lnPCGDP	−0.01	0.12	0.91	lnACCESS*lnPOLSYS	1.38	0.11	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Sierra Leone	lnGINI_DIS	0.92	0.09	0.00	lnACCESS	1.51	0.07	0.00
	lnPCGDP	3.53	0.36	0.00	lnPOLSYS	−3.65	0.56	0.00
	lnGINI_DIS*lnPCGDP	−0.99	0.11	0.00	lnACCESS*lnPOLSYS	1.54	0.29	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00

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Table 5 (*continued*).

Country	lnACCESS (Model 1)	Coef.	Drisc/Kraay Std. Err.	P > t	lnGINI_DIS (Model 4)	Coef.	Drisc/Kraay Std. Err.	P > t
South Africa	lnGINI_DIS	0.93	0.09	0.00	lnACCESS	0.98	0.00	0.00
	lnPCGDP	−2.16	0.32	0.00	lnPOLSYS	−7.08	0.16	0.00
	lnGINI_DIS*lnPCGDP	0.55	0.07	0.00	lnACCESS*lnPOLSYS	1.71	0.04	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Sudan	lnGINI_DIS	0.80	0.08	0.00	lnACCESS	1.02	0.02	0.00
	lnPCGDP	2.03	1.11	0.08	lnPOLSYS	−2.08	0.13	0.00
	lnGINI_DIS*lnPCGDP	−0.54	0.32	0.10	lnACCESS*lnPOLSYS	0.59	0.04	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Eswatini	lnGINI_DIS	2.44	1.00	0.02	lnACCESS	1.55	0.24	0.00
	lnPCGDP	−42.57	7.70	0.00	lnPOLSYS	−2.70	0.02	0.00
	lnGINI_DIS*lnPCGDP	10.29	1.79	0.00	lnACCESS*lnPOLSYS	1.05	0.16	0.00
	R-squared	0.97	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Tanzania	lnGINI_DIS	1.00	0.30	0.00	lnACCESS	1.33	0.12	0.00
	lnPCGDP	−17.33	3.80	0.00	lnPOLSYS	−4.17	0.15	0.00
	lnGINI_DIS*lnPCGDP	4.53	0.96	0.00	lnACCESS*lnPOLSYS	1.46	0.18	0.00
	R-squared	0.99	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
The Gambia	lnGINI_DIS	1.37	0.18	0.00	lnACCESS	1.23	0.06	0.00
	lnPCGDP	5.04	0.45	0.00	lnPOLSYS	−3.68	0.19	0.00
	lnGINI_DIS*lnPCGDP	−1.40	0.13	0.00	lnACCESS*lnPOLSYS	1.19	0.07	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Togo	lnGINI_DIS	0.26	0.44	0.56	lnACCESS	1.17	0.01	0.00
	lnPCGDP	−4.81	1.75	0.02	lnPOLSYS	−3.09	0.03	0.00
	lnGINI_DIS*lnPCGDP	1.40	0.40	0.01	lnACCESS*lnPOLSYS	0.97	0.01	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Uganda	lnGINI_DIS	−0.87	0.20	0.00	lnACCESS	1.17	0.23	0.00
	lnPCGDP	−9.80	3.32	0.01	lnPOLSYS	−2.55	0.21	0.00
	lnGINI_DIS*lnPCGDP	2.89	0.89	0.00	lnACCESS*lnPOLSYS	0.71	0.26	0.01
	R-squared	0.98	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Zambia	lnGINI_DIS	0.49	0.33	0.15	lnACCESS	1.44	0.02	0.00
	lnPCGDP	−2.01	3.91	0.61	lnPOLSYS	−5.53	0.15	0.00
	lnGINI_DIS*lnPCGDP	0.55	0.93	0.56	lnACCESS*lnPOLSYS	2.01	0.06	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00
Zimbabwe	lnGINI_DIS	1.01	0.04	0.00	lnACCESS	1.10	0.01	0.00
	lnPCGDP	1.61	0.27	0.00	lnPOLSYS	−2.93	0.41	0.00
	lnGINI_DIS*lnPCGDP	−0.43	0.07	0.00	lnACCESS*lnPOLSYS	0.84	0.11	0.00
	R-squared	1.00	Prob > F	0.00	R-squared	1.00	Prob > F	0.00

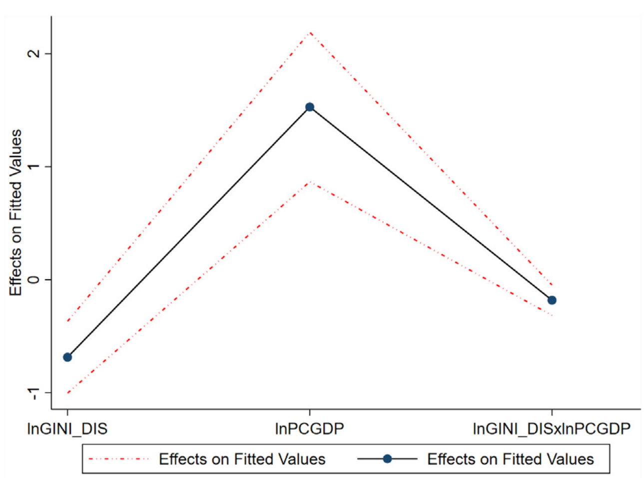

Fig. 2. Access model verification with the interaction between income inequality and income level. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs.

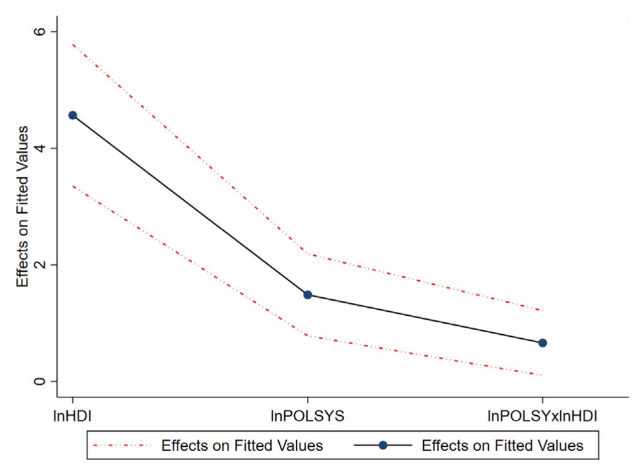

Fig. 3. Access model verification with the interaction between political system and human development index. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs.

5. Conclusion and policy implications

Access to electricity plays a domineering role in economic development, as such, the United Nations is on a crusade to ensure the accessibility of affordable and clean energy technologies by 2030 (SDG 7). Despite the global campaign, sub-Saharan Africa is still lagging behind and over depending on pollution-intensive and traditional solid biomass for cooking and heating purposes. Noxious indoor air pollution causing pneumonia, chronic obstruction pulmonary diseases, and among others have been attributed to the constant reliance on this vintage technology. This study contributes to the global debate by empirically testing the nexus between access to electricity, human development index, political system environment, income level, and income inequality. We further examined the impact of income inequality, access to

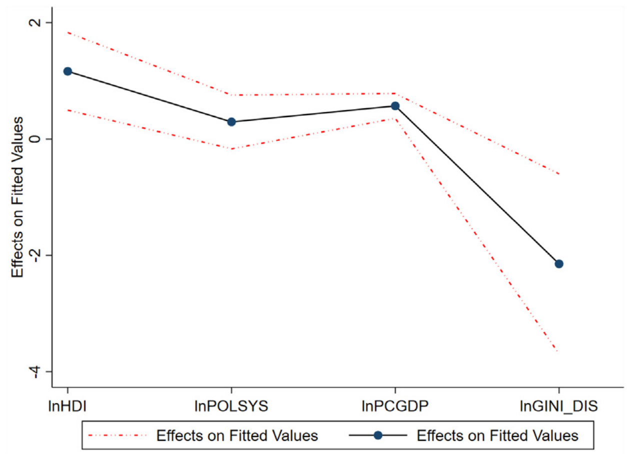

Fig. 4. Access to electricity model verification without interaction. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs.

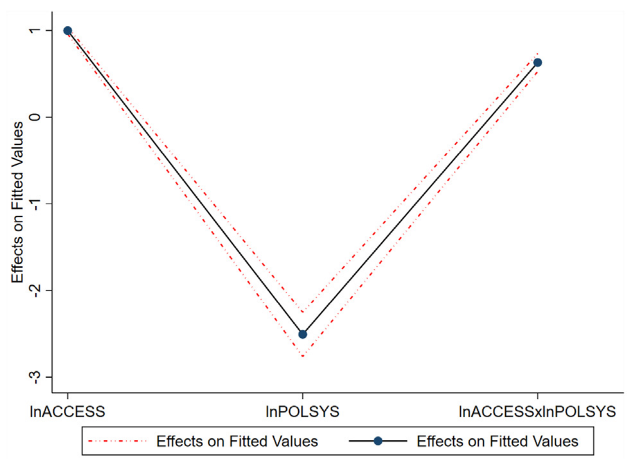

Fig. 5. Income inequality model verification. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs.

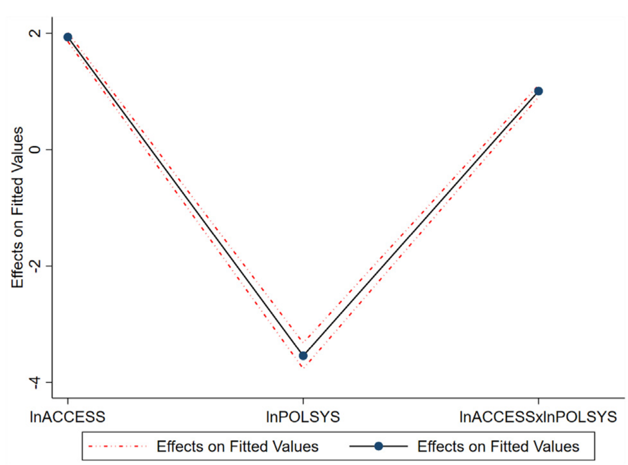

Fig. 6. Income level model verification. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs.

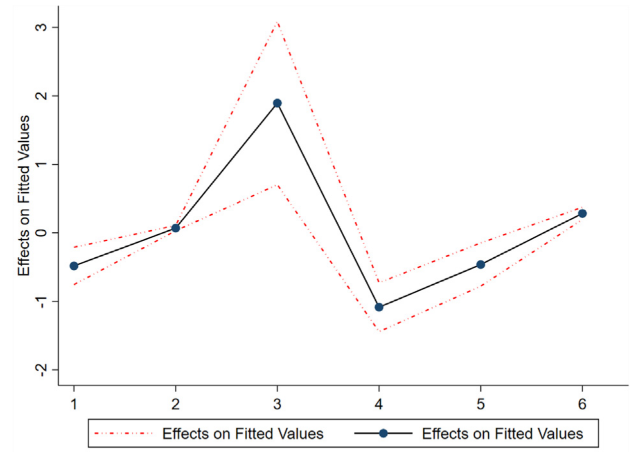

Fig. 7. Human development index model verification. NB: The red short-dash dot–dot represents the Conditional Marginal Effects with 95% CIs. Here, 1 is lnGINI_DIS, 2 is lnACCESS, 3 is lnPOLSYS, 4 is lnACCESSxlnPOLSYS, 5 is lnGINI_DISxlnPOLSYS, and 6 represents lnACCESSxlnPOLSYSxlnGINI_DIS.

electricity, governance environment, and among others on human development in sub-Saharan Africa from 1990–2017.

The study revealed that disparity in the distribution of income in sub-Saharan Africa has a negative effect on access to electricity while improvements in income levels and human development index have a positive impact on access to electricity. Evidence from the study demonstrated that income inequality reduces human development. As such, social protection policies and programs that minimize the vulnerability to poverty and reduce poverty through the promotion of effective and efficient labor markets, reduction of risk exposure, and the enhancement of socio-economic capacity to manage unemployment, discrimination, infirmity, disability, and retirement will increase income equality, hence, promote human development. A good political system environment in sub-Saharan Africa plays a critical role in human development. Environmental and socio-economic sustainability depends on good governance. Policy implications emanating from the study include:

- The introduction of policies that promote the incorporation of renewable energy technologies into the energy mix will promote economic growth and environmental quality.
- The institution of social intervention programs that reduce multidimensional poverty, improve gender equality, and decline income inequality is crucial in ensuring energy justice.

Data availability

Data used in this study is available in the public repository — with sources elaborated in the method section.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Samuel Asumadu Sarkodie: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Samuel Adams:** Conceptualization, Writing - original draft, Writing - review & editing.

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References

Adams, S., Klobodu, E.K.M., Apio, A., 2018. Renewable and non-renewable energy, regime type and economic growth. Renew. Energy 125, 755–767.

Adams, S., Klobodu, E.K.M., Opoku, E.E.O., 2016. Energy consumption, political regime and economic growth in sub-Saharan Africa. Energy Policy 96, 36–44.

Balachandra, P., 2011. Dynamics of rural energy access in India: An assessment. Energy 36, 5556–5567.

Breitung, J., 1999. The local power of some unit root tests for panel data. Discussion Papers, Interdisciplinary Research Project 373: Quantification and Simulation of Economic Processes.

Dabla-Norris, M.E., Kochhar, M.K., Suphaphiphat, M.N., Ricka, M.F., Tsounta, E., 2015. Causes and Consequences of Income Inequality: A Global Perspective. International Monetary Fund.

DiSano, J., 2002. Indicators of Sustainable Development: Guidelines and Methodologies. United Nations Department of Economic and Social Affairs, New York.

Driscoll, J.C., Kraay, A.C., 1998. Consistent covariance matrix estimation with spatially dependent panel data. Rev. Econ. Stat. 80, 549–560.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., 2011. Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Estache, A., 2008. Infrastructure and development: A survey of recent and upcoming issues. In: Rethinking Infrastructure for Development, Vol. 2. pp. 47–88.

Heffron, R.J., McCauley, D., 2014. Achieving sustainable supply chains through energy justice. Appl. Energy 123, 435–437.

Hughes, L., Lipscy, P.Y., 2013. The politics of energy. Annu. Rev. Polit. Sci. 16, 449–469.

IEA, 2016. Energy and air pollution: World energy outlook special report 2016. Retrieved from http://pure.iiasa.ac.at/id/eprint/13467/1/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf.

IEA, 2017. WEO-2017 special report: Energy access outlook. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf.

International Energy Agency, 2014. World energy outlook special report. Africa energy outlook. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

Kanagawa, M., Nakata, T., 2007. Analysis of the energy access improvement and its socio-economic impacts in rural areas of developing countries. Ecol. Econ. 62, 319–329.

Kanagawa, M., Nakata, T., 2008. Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. Energy Policy 36, 2016–2029.

Kunčič, A., 2014. Institutional quality dataset. J. Inst. Econ. 10, 135–161.

Levin, A., Lin, C.-F., Chu, C.-S.J., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. J. Econometrics 108, 1–24.

Martinez, D.M., Ebenhack, B.W., 2008. Understanding the role of energy consumption in human development through the use of saturation phenomena. Energy Policy 36, 1430–1435.

Mazur, A., 2011. Does increasing energy or electricity consun route to the model estimationmption improve quality of life in industrial nations?. Energy Policy 39, 2568–2572.

Niu, S., Jia, Y., Wang, W., He, R., Hu, L., Liu, Y., 2013. Electricity consumption and human development level: A comparative analysis based on panel data for 50 countries. Int. J. Electr. Power 53, 338–347.

Niu, S., Jia, Y., Ye, L., Dai, R., Li, N., 2016. Does electricity consumption improve residential living status in less developed regions? an empirical analysis using the quantile regression approach. Energy 95, 550–560.

Ouedraogo, N.S., 2013a. Energy consumption and economic growth: Evidence from the economic community of West African States (ECOWAS). Energy Econ. 36, 637–647.

Ouedraogo, N.S., 2013b. Energy consumption and human development: Evidence from a panel cointegration and error correction model. Energy 63, 28–41.

Owusu, P., Asumadu, S.S., 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng. 3, 1167990.

Pesaran, M.H., Im, K.S., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econometrics 115, 53–74.

Poloamina, I.D., Umoh, U.C., 2013. The determinants of electricity access in Sub-Saharan Africa. Empir. Econom. Quant. Econ. Lett. 2, 65–74.

Romero-Jordán, D., Del Río, P., Peñasco, C., 2016. An analysis of the welfare and distributive implications of factors influencing household electricity consumption. Energy Policy 88, 361–370.

Sarkodie, A.S., 2018. The invisible hand and EKC hypothesis: What are the drivers of environmental degradation and pollution in Africa? Environ. Sci. Pollut. Res. 25, 21993–22022.

Sarkodie, S.A., Adams, S., 2018. Renewable energy, nuclear energy, and environmental pollution: Accounting for political institutional quality in South Africa. Sci. Total Environ. 643, 1590–1601.

Sarkodie, S.A., Adom, P.K., 2018. Determinants of energy consumption in Kenya: A NIPALS approach. Energy 159, 696–705.

Sarkodie, S.A., Strezov, V., 2019. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci. Total Environ. 646, 862–871.

Sen, A.K., 1997. From income inequality to economic inequality. South. Econ. J. 64, 384–401.

Shahbaz, M., Khan, S., Tahir, M.I., 2013. The dynamic links between energy consumption, economic growth, financial development and trade in China: Fresh evidence from multivariate framework analysis. Energy Econ. 40, 8–21.

Solt, F., 2016. The standardized world income inequality database. Soc. Sci. Q. 97, 1267–1281.

Sovacool, B.K., Dworkin, M.H., 2015. Energy justice: Conceptual insights and practical applications. Appl. Energy 142, 435–444.

Starr, M.K., 1972. Production Management; Systems and Synthesis. Prentice Hall.

Stiglitz, J., Sen, A., Fitoussi, J.-P., 2009. The measurement of economic performance and social progress revisited. In: Reflections and Overview. Commission on the Measurement of Economic Performance and Social Progress, Paris.

Teorell, J., Dahlberg, Stefan, Holmberg, Sören, Rothstein, Bo, Pachon, Natalia Alvarado, Svensson, Richard, 2020. The Quality of Government Standard Dataset, Jan20 ed. University of Gothenburg: The Quality of Government Institute.

UNDP, 2016. Human development indicators. Retrieved from http://hdr.undp.org/.

United Nations, 2015. Sustainable development goals. Retrieved from https://sustainabledevelopment.un.org/?menu=1300.

Van Beers, C., Strand, J., 2013. Political Determinants of Fossil Fuel Pricing. The World Bank.

Wilkinson, R.G., Pickett, K.E., De Vogli, R., 2010. Equality, sustainability, and quality of life. BMJ 341, c5816.

World Bank, 2015. Data. Retrieved from http://data.worldbank.org/.

World Bank, 2018. World development indicators. Retrieved from http://data.worldbank.org/country.