Energy Nexus 5 (2022) 100034

Contents lists available at ScienceDirect

Energy Nexus

journal homepage: www.elsevier.com/locate/nexus

Impact of energy poverty on education inequality and infant mortality in some selected African countries

Ibrahim Kekere Sule[a], Abdulmalik M. Yusuf[a,b,*], Muhammad-Kabir Salihu[a,c]

[a] Department of Economics, Ahmadu Bello University, Zaria, Nigeria
[b] University of Cheikh Anta Diop, WASCAL-Climate Change Economics, BP 5683, Dakar, Senegal
[c] Department of Economics, Lancaster University Management School, Lancaster LA1 4YX, United Kingdom

A R T I C L E I N F O

JEL classification:
Q01
Q38
J18
Q35
Q40

Keywords:
Energy poverty
Socioeconomic variable
Health
Quality of life
Africa

A B S T R A C T

Energy poverty has far-reaching socioeconomic consequences on household wellbeing. Fuel cost, low incomes and energy inefficient dwellings, which are key constituents of energy poverty have implication on under 5 mortality rate and inequality in education. This study examined the link between energy poverty, under 5 mortality and inequality in education using data for 33 African countries. Empirical evidence from this study is based on panel cointegration, causality and fully modified ordinary least squares (FMOLS). The result suggests the existence of cointegration between energy poverty and under 5 mortality as well as between energy poverty and inequality in education. The result also suggests a unidirectional causality running energy poverty to under 5 mortality and from energy poverty to education inequality. The FMOLS result show that energy poverty is negatively and significantly related to under 5 mortality and inequality in education. The insights from this study are informative to policy makers among these African countries to support decision making around energy poverty in order to optimize the health and wellbeing of families. An increase in household access to energy through state intervention may reduce its impact on under 5 mortality, as well as reduce the gap in educational opportunities between the rural-poor and urban centers.

1. Introduction

The critical role of energy in an economy in addition to the surging prices of energy traversing over numerous countries worldwide has stimulated interests in energy poverty among policymakers, political institutions and academics in recent years. As simply explained in the literature, energy poverty implies households' inability to provide for basic domestic energy needs, a challenge which is not only common to developing countries, but is also present in developed nations to a large extent, with European countries' energy poverty rates estimated to be as high as 40% [[11],[71]]. The energy poor constitute between 1.4 billion and 3 billion people without access to useful energy for domestic use and/or mechanical use. The energy poor are categorized into two groups of people. The first are the highly vulnerable, comprising over 1.4 billion people living on less than $1.15/day, without access to safe, reliable and efficient energy sources for domestic use (cooking and lightening) and/or for mechanical use. The second group comprises over 3 billion people (nearly 50% of the World's population) who depend on the use of harmful energy sources such as biomass-generated energy for cooking and heating (United Nations Secretary General Advisory Group on Energy and Climate Change, [75]). This biomass generated energy is usually obtained by burning animal wastes (animal dung), crop residues, wood or raw coal. The smoke coming from the burning of such biomass-related substances negatively impact on human health by way of inducing premature deaths, due to respiratory infections inflicted on over 2 million people as a result, most of whom are women and children. More so, the biomass-generated energy doesn't provide the basic energy forms required even in rural agriculture for irrigation, ploughing, harrowing, harvesting, grinding, milling, food processing, etc. Income generation via small businesses needs energy for transportation and distribution of goods and services to markets and also for telecommunications. In communities and schools, installed water treatment plants requires energy to provide quality drinking water for people. Energy is also required for refrigerating important drugs and vaccines. In addition, energy is critical for lighting and heating in schools, as well as at home to allow students complete their homework (United Nations Secretary General Advisory Group on Energy and Climate Change, [75]). According to a joint report by the United Nations Development Programme (UNDP) and the World Health Organization (WHO), while an estimated 28% of people residing in developing countries are without access to electricity, the number is 79% for those in the least-developed countries (LDCs). Generally, the lack of access to critical energy sources in LDCs

* Corresponding author at: Department of Economics, Ahmadu Bello University, Zaria, Nigeria.
E-mail address: yuussuufu@gmail.com (A.M. Yusuf).

https://doi.org/10.1016/j.nexus.2021.100034
Received 18 September 2021; Received in revised form 16 November 2021; Accepted 28 November 2021
Available online 2 December 2021

has greatly contributed to creating and compounding their energy crisis, thereby keeping them trapped at the base of the energy ladder [39]. LDCs are countries characterized as economically and socially deprived, with income per capita of less than US$905. In addition, LDCs are also known to have weak human assets (mortality, illiteracy and low enrollment), high exposure to shocks and disasters, trade shocks, economic smallness and economic remoteness. Since traditional energy sources are usually harmful, unproductive and inefficient, it calls for an urgent need to introduce Appropriate Sustainable Energy Technologies (ASETs) to bridge the gap between modern/advanced technologies (which are usually highly capital-intensive) and the energy poor's traditional subsistence technologies. This will promote the drive towards sustainable development in LDCs [[21],[55]]. Energy affects and influences nearly all aspects of the human and social world [[63],[47]]. As hypothesized by Herbert Spencer, the society's ability to harness energy determines what it can produce, and hence, the basis for social progress and differences in the level of development among societies [48]. This means that, the ability or inability of a society to harness energy constrains the society's capacity to grow and develop [23]. This follows further to imply that the inability to access energy breeds poverty, thereby forcing the energy poor to rely on harmful and inefficient biomass-generated energy sources for daily survival.

Global estimates show that 2.4 billion people still survive on earth without electricity, or at least have access to unreliable and irregular electricity systems (Savacool et al., [68]). For example, in the United Kingdom, 10% of households are said to be experiencing fuel poverty, most of whom have been linked with related health complications, while in France, the number of households estimated to be in energy poverty is put at around 3.8 million ([38]; Burlinson et al.[15]). The United Kingdom's government spends around £1.3 billion yearly in the provision of energy poverty-linked health services for the elderly people (Age UK, [1]). According to a UNDP report in 2014, Sub-Saharan Africa, Latin America and South Asia are among the three regions in the world that suffer most from energy poverty. Energy constitutes the most significant inputs for livelihood sustenance. At the most basic level, it provides cooked food, boiled water and warmth, conventional energy, etc. Besides the high cost of conventional energy, most people use biomass as their main energy source. The increasing shortage of biomass constitutes an additional burden on access to energy. However, the use of biomass has a number of health implications due to low fuel quality and the emission of smoke and particulates known to have negative effect on health. Other dimension of energy poverty is that less water is boiled for drinking and other hygiene purposes, thus, increasing the likelihood of water borne disease. Poor health reduces the ability of people to improve their livelihood by preventing them from working effectively. Similarly, poor access to energy affects children's learning outcomes as it affects both children and adult from studying at night. This has negative impact on their educational performance which may work against sustainable livelihood in the future [64]. As evident from Fig. 1, the double-sided arrow indicates that causality runs in both ways.

Aside monetary costs, there are several other socioeconomic consequences associated with energy poverty which have huge bearings on the social wellbeing, productivity and health of households ([[9],[62]]; Awaworyi-Churchill et al., [7]). Though a few studies in the literature had addressed several aspects of energy poverty, some questions are still yet to be answered. In the first instance, a number of studies had challenged the existing measures of energy poverty as well as raised issues surrounding the conceptualizations of energy poverty (see, [[58],[2]]). However, the lack of agreement among scholars on a standard conceptual and methodological framework to adopt has made it difficult for policymakers to tackle energy poverty issues [[65],[2]]. Another issue pertains understanding the evolutions in energy poverty, with many studies placing more attention to energy efficiency, energy prices and income as key determinants of energy poverty (Hills, 2012; [[52],[41]]). Social and cultural factors like ethnic differences and trust have been seen to be key determinants of energy poverty and could give more insights on potential determinants of the phenomenon based on recent evidence (Awaworyi-Churchill & Smyth, [6]). In addition, studies centered around the impact of targeted policies and programs on energy poverty are nonexistent in the literature. This is so because policymakers in some parts of the globe have come up with numerous interventions and programs to tackle energy poverty and very little has been known about the impacts of these interventions [3]. Also, pertaining to the effects of energy poverty and its implications on some important sectors or aspects of an economy, a lot is yet to be uncovered in this area. While some emerging studies paid more attention to energy poverty impacts on wellbeing and health, others gave much attention to its impacts on climate change [[16],[17]]. However, as have been highlighted and hypothesized conceptually in the literature, energy poverty has several potential effects on a number of socioeconomic factors [70], this calls for the need to carry out studies on how energy poverty affects other outcomes beyond wellbeing and health. A study has also shown that economic, social and energy insecurity set limitations to the provision of sustainable, fair and equitable energy for abandoned communities [10]. More so, even studies that had looked at the impacts of energy poverty on health and wellbeing had focused mainly on European Countries as well as globally [[12],[9],[72],[76],[34],[42],[53]]. On this basis and to the best of our review, we have not come across any study that had examined the impact of energy poverty on Education Inequality and Infant Mortality in Africa. This study aims to contribute to filling this gap in the literature. The findings of this study provide relevant information to policy makers among the selected African countries to support decision making around energy poverty.

The paper is structured into five sections. The first section provides an introduction while section two gives the review of literature. Section three presents the methodology used in the study. In section four, we present the empirical findings and discussions of the results and section five concludes the study.

2. The literature

Energy is key to many aspects of socio-economic freedom. The major obstacle to development in many parts of Africa and other developing countries is lack of access to affordable energy. This apparent lack of access to affordable energy, environmentally friendly and reliable energy services constitute an important impediment to social, human and economic development and the achievement of Sustainable Development Goals (SDGs). In Africa, energy access remained one of the most forgotten development goals despite its central role as an enabler of other key development goals such as improved health services and education [25]. As such, universal access to energy is far from being achieved anywhere in the developing world, including many African countries.

As highlighted in several studies, energy poverty is severe in many developing countries ([27]; Awaworyi et al. [7]). There is no universally accepted definition of energy poverty, as the concept is evolving and still being highly debated [[13],[27]]. Despite the conceptual issues in what constitutes energy poverty, it's mostly agreed by economist that energy poverty is the inability of households to meet basic energy needs [71]. In other words, traditional biomass usage constitutes the major source of energy for those experiencing energy poverty, who also spend a large chunk of their time collecting wood and dung for their basic energy needs [[18],[27]]. According to EU guidance on energy poverty, it summarizes the concept as a combination of low income, high expenditure of disposable income on energy and poor energy efficiency, especially as regards the performance of buildings [31]. From this definition, it is evident that cause-effect is implicit and core to the definition of energy poverty. In other words, this definition incorporates causes (like low income) and effects (energy deprivation). The coexistence of the cause-effect lies at the heart of the ambiguity inherent in the definitions and metrics used in conceptualizing the definition of energy poverty in the last few decades [8]. Energy is vital to the wellbeing and general standard of living of people, as such, the type, extent, as well

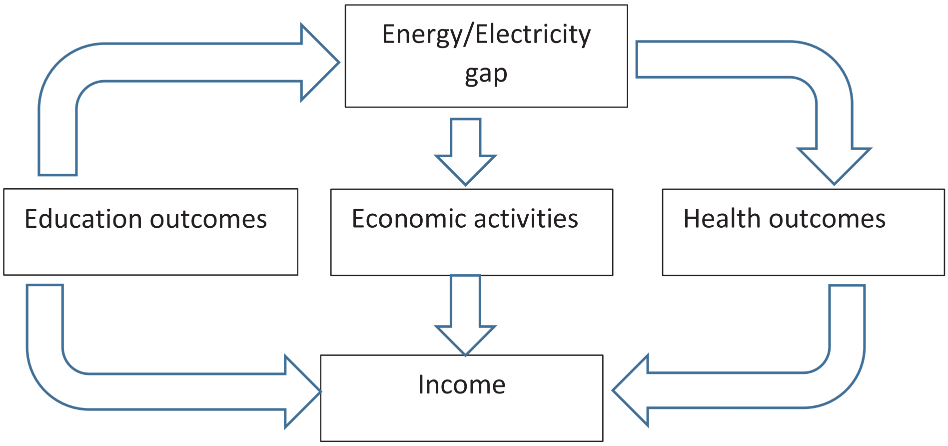

Fig. 1. Flow chart showing energy poverty-education-health nexus (source: authors construct).

as access to energy determines the wealth status of the inhabitants of any country [[56],[4],[46],[30]]. In other words, clean energy is key to sustainable development and a more friendly environmental because it has fewer negative health impacts and does not contribute to climate change [[35],[29]].

Due to this significant impact of energy poverty on households and society in general, the concept is gaining unprecedented momentum among scholars and policy makers alike [[27],[37],[7]]. Besides issues relating to economic development [[18],[22]], energy poverty is an important constituent of sustainable development issues [[52],[69],[27]]. Energy poverty is also linked to several social issues ([36]; Awaworyi et al., [[7],[42]]). Several dimensions of the impact of energy poverty have been addressed in the literature, for instance some studies focused on wellbeing and health [[72],[36],[42]]. Some recent studies have also mentioned the potential relationship between energy poverty and gender inequality. For instance, Robinson [61], Aristondo and Onaindia [5], and Moniruzzaman & Day [51] find that energy poverty seemed to differ according to gender. Nguyen et al., [54] investigates the influence of energy poverty reduction on gender inequality, using a sample of 51 developing countries from 2002 to 2017 and considering four dimensions: employment, health, education, and socio-political-economic rights. By applying a two-step system generalized method of moments, the result shows that a reduction in energy poverty appears to increase employment opportunities for women, especially in industry and service sectors, which results in an improvement in the number of female wage and salaried workers in comparison with their male counterparts.

The interlinkages between energy, poverty and inequality have been widely acknowledged in the literature. Poor people energy outlook 2010 framed lack of access to energy service as a form, an outcome and a cause of poverty. Because it restricts human capabilities to meet their needs and full potentials, it is a form of poverty. Also, it is an outcome because low-income earners are limited in their abilities to afford goods and services that high income earners can afford. Finally, it is a cause because it reinforces constraint in the income generation potential (United [74]). To put it succinctly, “a vicious circle is created whereby a lack of energy access leads to limited income-earning capability, which reduces purchasing power, which in turn limits the access to energy that could improve incomes” [60]. In addition, lack of access to energy, the lack of clean fuels and technologies for cooking, the lack of minimum energy for each individual, or minimum income for energy spending on basic necessities constitutes the building block of energy poverty [[58],[27]]. Income inequality is essentially the gap between high-income earners and low-income earners. As such, an increase in the incidence of energy poverty implies a dramatic rise in the number of people without access to electricity and energy for necessity which leads to deteriorating living condition for the most vulnerable groups [[32],[54]]. Energy poverty has far-reaching implication on health. For instance, apart from health implication of biomass due to low fuel quality and emission of smoke and particulate, energy poverty implies that less water is boiled for drinking, thus, increasing the likelihood of water borne diseases with implications on infant mortality. Poor access to energy also affects learning outcomes as it prevents both children and adults from studying effectively at night. This has negative impact on their educational performance which may cause unequal access to education. As a result, energy poverty is found to be inextricably linked to unequal access to education especially for rural areas with high incidence of energy poverty. Interestingly, no attempt has been made in the empirical literature to explore the linkages between energy poverty, education inequality and infant mortality in Africa. In the works of Nguyen et al., [54], their findings show that focusing on improving financial development can be very effective in the reduction of energy poverty. This was true for low-and-lower-middle income countries. Another study on Puerto Rico’s long blackout after Hurricane Maria showed a debt-energy nexus which resulted from increased borrowing by the Puerto Rican government in the United States to restore electricity back to the affected citizens [67]. Finally, a number of other studies had looked at the energy-poverty-gender nexus [[24],[66],[43],[44]]. Findings show that women are more affected negatively in terms of access to clean energy sources.

3. Econometric methodology and model

3.1. Panel cointegration

The panel cointegration method is often used to examine the long run cointegrating relationship between variables. As such, this study adopts this method to investigate the cointegrating relationship among energy poverty, under 5 mortality and inequality in education. The hypothesis can be presented in the form of two linear relationship:

$$U5MR = f(ENP) \tag{1}$$

$$IED = f(ENP) \tag{2}$$

The specification of equation follows a baseline econometric model expressed as:

$$In(Y)_{i,t} = \alpha_i + In(X)_{i,t}\beta + \in_{i,t},\ i = 1 - - - - N,\ t = 1 - - - - - T \tag{3}$$

Similarly, the specification of Eq. (2) follow the model expressed as:

$$In(Y)_{i,t} = \alpha_i + In(X)_{i,t}\beta + \in_{i,t},\ i = 1 - - - - N,\ t = 1 - - - - - T \tag{4}$$

Where $In(Y)$ in both Eqs. (3) and (4) are logarithmic transformation of the dependent variable, that is, under 5 mortality (U5M) and inequality in education (IED) respectively. α_i denote the country fixed effects, $In(X)$ represent the independent variables which includes energy poverty (ENP) proxied with access to electricity as a percentage of population. β denotes the coefficient estimate, $\in$ is the error term, i represents the cross-sectional units and t is the time period.

Table 1
Data used.

Representation	Variables	Definition/unit of measurement
ENP	Energy poverty	Access to electricity as a% of population
IED	Inequality in education	Based on data from household survey estimated using the Atkinson inequality index
U5M	Under 5 mortality rates	Death per thousand live births

Source: UNICEF, HDI and WDI database.

3.2. Panel granger causality

The existence of a long-run cointegration among our variables of interest necessitates the need to explore Granger causality. To define the direction of causality among our variables, the equation to analyze the relationship between under 5 mortality (U5M) and energy poverty (ENP), as well as between inequality in education (IED) and energy poverty can be stated as:

$$\Delta \boldsymbol{InU5M}_{it} = \propto + \sum_{j=1}^{j} \beta_j \Delta \boldsymbol{InU5M}_{it-j} + \sum_{j=1}^{j} \delta_j \Delta \boldsymbol{InENP}_{it-j} + \in_{it} \quad (5)$$

$$\Delta \boldsymbol{InIED}_{it} = \propto + \sum_{k=1}^{k} \gamma_k \Delta \boldsymbol{InIED}_{it-k} + \sum_{k=1}^{k} \vartheta_k \Delta \boldsymbol{InENP}_{it-k} + \in_{it} \quad (6)$$

Where $i = 1,$ ———, N refers to country, $t = 1,$ ————, T refers to year and $\in$ is the stochastic error term. To apply the Granger-causality test, all the variables must be stationary. In Eq. (5), $\Delta InENP$ Granger-cause $\Delta InU5M$ if the past values of $\Delta InENP$ can predict the current values of $\Delta InU5M$, even when the past values of $\Delta InU5M$ have been included in the model. In other words, $\Delta InENP$ Granger-cause $\Delta InU5M$ if the coefficient δ_j jointly defer statistically from zero. Causality in the opposite direction can be tested by swapping the two variables. Similarly, to test if $\Delta InENP$ Granger-cause $\Delta InIED$ in Eq. (6), the coefficient ϑ_k must be jointly equal to zero. In line with Dumitrescu-Hurlin (2012) method of Granger causality test, all coefficients can vary across countries but are invariant over time.

3.3. Data description

We assemble data of 33 African countries (Benin, Burkina Faso, Coted'Ivoire, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bisau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Ruanda, Senegal, Sierra Leone, Tanzania, Togo, Trinidad and Tobago, Tunisia, Uganda, Zimbabwe, Egypt, Gabon, Mauritius, Namibia, South Sudan and South Africa). The study used yearly data from 2010 to 2017, comprising data for under 5 mortality rate which was sourced from UNICEF global database (http://data.unicef.org). Inequality in education data was obtained from Human Development Report (http://hdr.undp.org), while data on access to electricity (% of population) was obtained from World Development Indicator (WDI). The three variables used in this study take a logarithm form. To examine the relationship between energy poverty, under 5 mortality rate and inequality in education, this study proposed three tests which includes panel unit root test, the panel cointegration test, panel causality test and the estimation of fully modified ordinary least squares (FMOLS).

4. Discussion of results

Table 2 presents the descriptive statistics for the variables used in the estimations. The result shows that there is substantial variation in variables, as indicated in the standard deviation which suggest that the dispersion around their averages is relatively wide. Also, the kurtosis that measures the peakedness or flatness of the series distribution indicates that the series peaked to the surface or leptokurtic relative to the normal distribution. The skewness value for U5M and ENP have positive skewness (long right tail) which indicates more-higher values above sample average, while that of inequality in education (IED) is negative (long left tail) indicating more lower values than the sample average.

Next, we performed the unit root test to ascertain if our variables of interest have unit root or not. In the literature, a number of panel unit root tests have been proposed which include Maddala and Wu [45], Breitung [14], Hadri [28] Choi [20], Levin et al. [40] and Im et al. [33]. Levin et al. [40] utilized the generalized individual unit root test to panels with heterogeneous serially correlated errors, fixed effects and individual deterministic trends. The drawback of the method is that it requires a homogeneous autoregressive root under the alternative hypothesis. In contrast, Im et al. [33] panel unit root test allows for a heterogeneous autoregressive coefficient under the alternative hypothesis. However, both the Levin et al. [40] and Im et al. [33] tests suffer from a dramatic loss of power when individual specific trends are included due to bias correction. The Fisher type panel unit root test as proposed by Maddala and Wu [45] and Choi [20], combines the probability values from individual unit root tests. The test neither requires a balanced panel nor identical lag lengths in the individual regressions. As such, our interpretation of unit root result in this study is based on MW panel unit root test with intercept and time trend, since our data set exhibit clear trends. The result of the panel unit root test as presented in Table 3 show that our variables are stationary at first difference, which suggest the possibility of cointegration among our series.

Tables 4 and 5 summarizes the results of Pedroni's panel cointegration test. The cointegration test indicate a significant cointegrating relationship between inequality in education (EDI) and energy poverty (ENP). Similarly, it also shows a significant cointegration between under 5 mortality (U5M) and energy poverty (ENP). In the relationship between education inequality and energy poverty (Table 4), the result show that the null hypothesis of no cointegration is strongly rejected by five statistics with the exception of panel v-statistics and panel group rho-statistic at the 1, 5 and 10% significance level. On the relationship between under 5 mortality (U5M) and energy poverty, the null hypothesis of no cointegration is rejected in all except for the panel rho-statistic and group rho-statistic. Thus, we conclude that a long-run relationship exists between energy poverty, inequality in education and under 5 mortality rates.

Since the variables in the two equations are cointegrated, we proceed to estimate the long run coefficient using the panel fully modified OLS (FMOLS) proposed by Chiang and Kao [19]. Besides proving the existence of cointegrated relationship and calculating individual samples and panel estimators, the FMOLS technique can correct for the deviation caused by correlation and endogeneity between variables inherent in the traditional OLS estimation ([59]; Westerlund, 2007). According to Pedroni [59], the FMOLS technique as a non-parametric approach has advantage and can produce consistent result in small sample. Here, the full sample coefficients of ENP in both model 1 & 2 are −0.1925 and −0.4237 respectively. These results implies that a 1% increase in access to electricity will reduce infant mortality by 0.19%. This implies that energy poverty or reduction in access to electricity indicates that less water is boiled for drinking and for other hygiene purposes, thus, increasing the likelihood of waterborne diseases among children. As children spend most of their time indoors, the condition of their home matters a lot for their wellbeing. Studies have shown that the condition of homes have direct and indirect impact on inhabitant's health (see [26]). Our result is in line with previous studies that linked poor access to energy to child

Table 2
Descriptive statistics.

Variable	No of obs	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
ENP	244	44.04	36.89	100.00	4.10	28.91	0.75	2.32
IED	244	33.84713	36.80000	49.60	6.60	11.02	−0.81307	2.83
U5M	244	68,831.46	39,558.00	817,137.0	175.00	135,954.9	4.486140	23.23

Source: Authors construct based on estimated data.

Table 3
Panel unit root result.

	LLC		Im, Pesaran & Shin		ADF-Fisher Chi-square	
	Level	1st Diff	Level	1st Diff	Level	1st Diff
U5M	−4.75	−16.8	0.35	−6.78	69.85	−77.59
Prob	0.00	0.00	0.64	0.06	0.29	0.08
ENP	11..09	−16.89	−0.56	−28.77	73.21	−153.04
Prob	0.00	0.00	0.29	0.00	0.22	0.00
EDIN	−22.1	−14.99	−0.52	−3.31	67.32	−83.4
Prob	0.09	0.00	0.30	0.00	0.21	0.06

Source: Authors construct based on estimated data.

Table 4
Pedroni cointegration test result (EDI and ENP).

With Trend and Intercept					
Within-dimension	Statistics	Prob	Between-dimension		
Panel v-Statistic	−14.04	1.00		Statistics	Prob
Panel rho-Statistic	−1.27	0.10	Group rho-Statistic	5.13	1.00
Panel PP-Statistic	−9.54	0.00	Group PP-Statistic	−7.07	0.05
Panel ADF-Statistic	−4.20	0.04	Group ADF-Statistic	−4.73	0.00

Note: The null hypothesis is that the variables are not cointegrated. Under the null tests, all variables are distributed normal (0, 1).
Source: Authors construct based on estimated data.

Table 5
Pedroni cointegration test result (U5M and ENP).

With Trend and Intercept					
Within-dimension	Statistic	Prob.	Between-dimension		
Panel v-Statistic	−43.10	0.00		Statistic	Prob.
Panel rho-Statistic	4.44	1.00	Group rho-Statistic	6.10	1.00
Panel PP-Statistic	−2.51	0.09	Group PP-Statistic	−3.06	0.00
Panel ADF-Statistic	−1.49	0.07	Group ADF-Statistic	−1.67	0.04

Note: The null hypothesis is that the variables are not cointegrated. Under the null tests, all variables are distributed normal (0, 1).
Source: Authors construct based on estimated data.

Table 6
Long run estimate with FMOLS.

Dependent Variable: Under 5 Mortality	Dependent Variable: Inequality in Education
Model 1: U5M= F (ENP)	Model 2: IED= F (ENP)
−0.1925**[−5.4712]	−0.4237*[−2.7811]

Note: *' ** indicates 1% and 5% respectively, t-statistics is given in bracket []. Abbreviations: U5M= Under 5 mortality; IED= Inequality in education; ENP= Energy poverty.
Source: Authors construct based on estimated data.

Table 7
Panel granger causality test (Full sample).

	$\Delta InENP \rightarrow \Delta InU5M$	$\Delta InENP \rightarrow \Delta InIED$
$\ddot{Z}$ Statistics	2.160**	1.082*
(p-values)	0.078	0.000
	$\Delta InU5M \rightarrow \Delta InENP$	$\Delta InIED \rightarrow \Delta InENP$
$\ddot{Z}$ Statistics	1.781	0.560
(p-values)	0.214	0.116

Notes: *, ** significant at 1% and 5% level.
Source: Authors construct based on estimated data.

respiratory illness (see, [[73],[49],[50]]). This result suggests that access to energy is crucial to reducing under 5 mortality.

Also, the result in Table 6 reveals that as access to energy increases by 1%, inequality in education reduces by 0.42%. Poor access to energy affects children's learning outcomes as it prevents both children and adult from studying at night. This has negative impact on their educational performance which may work against sustainable livelihood in the future. Unequal access to energy due to income differentials as well as the differences in access to electricity between the rural poor and urban areas could lead to unequal opportunities in terms of access to educational resources, thereby widening the gap between rural and urban centers. Our result corresponds with Oum [57] who finds that energy poverty negatively impacts households' average school years and health status in Lao PDR.

Table 7 shows the results of the Granger causality test on the full sample generated from R Studio. We test for both directions of causality, first from $\Delta InENP$ to $\Delta InU5M$, then from $\Delta InU5M$ to $\Delta InENP$. Then we repeat the process and run a bidirectional causality from $\Delta InENP$ to $\Delta InIED$, and vice versa. In the first row, the result show that at the 10% level of significance, the null hypothesis that energy poverty ($\Delta InENP$) does not Granger cause under 5 mortality ($\Delta InU5M$) can be rejected, indicating that causality runs from energy poverty to under 5 mortality. However, the null hypothesis that causality runs from $\Delta InU5M$ to $\Delta InENP$ cannot be rejected. Similarly, the null hypothesis that $\Delta InENP$ does not Ganger-cause $\Delta InIED$ is rejected at the 1% significance level. This implies that energy poverty Granger-cause inequality in education.

5. Conclusion and policy implication

The interaction between fuel costs, low incomes and energy inefficient dwellings constitutes the building blocks of energy poverty and have been identified as public health concern. This is so because they have far-reaching consequences on socioeconomic outcome of households such as education and health, especially under 5 mortality rates. As such, this study examined the link between energy poverty ($\Delta InENP$), under 5 mortality ($\Delta InU5M$) and inequality in education ($\Delta InIED$) using data for 33 African countries. Empirical evidence from this study was based on panel cointegration, causality and fully modified OLS (FMOLS). The results suggest the existence of cointegration between $\Delta InENP$ and $\Delta InU5M$, as well as between $\Delta InENP$ and $\Delta InIED$. The result also suggests a unidirectional causality running from $\Delta InENP$ to $\Delta InU5M$, and from $\Delta InENP$ to $\Delta InIED$. The FMOLS result show that energy poverty is negatively and significantly related to under 5 mortality and inequality in education. The insights from this study are informative to policy makers among these African countries to support decision making around reducing energy poverty in other to optimize the health and wellbeing of families. An increase in household access to energy through state intervention may reduce its impact on under 5 mortality, as well as reduce the gap in educational opportunities between the rural-poor and urban centers.

Declaration of Competing Interest

There is no conflict of interest among authors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nexus.2021.100034.

References

[1] Age UKThe Cost of the Cold, Age UK, 2012.
[2] K. Alhassan, Energy-poverty nexus: conceptual framework analysis of cooking fuel consumption in Ghanaian households, Dev. Ctry. Stud. 8 (11) (2018).
[3] G.G. Alvarez, R.S.J. Tol, The impact of the bono social de electricidad on energy poverty in Spain, Working Paper Series 0420,, Department of Economics, University of Sussex Business School, 2020.
[4] K. Araújo, The emerging field of energy transitions: progress, challenges, and opportunities, Energy Res. Soc. Sci. 1 (2014) 112–121.
[5] O. Aristondo, E. Onaindia, Inequality of energy poverty between groups in Spain, Energy 153 (2018) 431–442, doi:10.1016/j.energy.2018.04.029.
[6] S. Awaworyi Churchill, R Smyth, Ethnic diversity, energy poverty and the mediating role of trust: evidence from household panel data for Australia, Energy Econ. 86 (2020) 104663.
[7] S. Awaworyi Churchill, R. Smyth, L Farrell, Fuel poverty and subjective wellbeing, Energy Econ. 86 (2020) 104650, doi:10.1016/j.eneco.2019.104650.
[8] R. Bardazzi, L. Bortolotti, M.G. Pazienza, To eat and not to heat? Energy poverty and income inequality in Italian regions, Energy Res. Soc. Sci. 73 (2021) 101946, doi:10.1016/j.erss.2021.101946.
[9] Biermann, P. (2016). *How fuel poverty affects subjective well-being: Panel evidence from Germany* (Vol. 395, No. 16). Oldenburg Discussion Papers in Economics.
[10] S. Biswas, *Creating Social Value of Energy at the Grassroots: Investigating the Energy-Poverty Nexus and Co-Producing Solutions For Energy Thriving* (Doctoral Dissertation, Arizona State University, 2020.
[11] S. Bouzarovski, Energy poverty in the European Union: landscapes of vulnerability, Wiley Interdiscip. Rev. Energy Environ. 3 (3) (2014) 276–289.
[12] S. Bouzarovski, S. Petrova, A global perspective on domestic energy deprivation: overcoming the energy poverty-fuel poverty binary, Energy Res. Soc. Sci. 10 (2015) 31–40.
[13] S. Bouzarovski, S. Petrova, Robert Sarlamanov, Energy poverty policies in the EU: a critical perspective, Energy Policy 49 (2012) 76–82, doi:10.1016/j.
[14] J. Breitung, The local power of some unit root tests for panel data, Nonstationary Panels Panel Cointegration Dyn. Panels 15 (2000) 161–177.
[15] A. Burlinson, M. Giulietti, G. Battisti, The elephant in the energy room: establishing the nexus between housing poverty and fuel poverty, Energy Econ. 72 (2018) 135–144.
[16] C.E. Casillas, D.M. Kammen, The energy-poverty-climate nexus, Science 330 (6008) (2010) 1181–1182.
[17] S. Chakravarty, M. Tavoni, Energy poverty alleviation and climate change mitigation: is there a trade off? Energy Econ. 40 (2013) S67–S73.
[18] edited by J.M. Chevalier, N.S. Ouédraogo, J.M. Chevalier, Energy poverty and economic development, in: The New Energy Crisis: Climate, Economics and Geopolitics, Palgrave Macmillan UK, 2009, pp. 115–144. edited by.
[19] M.H. Chiang, C. Kao, On the estimation and inference of a cointegrated regression in panel data, Adv. Econ. 20 (2000) 179–222.
[20] I. Choi, Unit root tests for panel data, J. Int. Money Financ. (2001) 249–272 pages.
[21] Community Development Policy, (2011). UN Office of the high representative for the least developed countries, landlocked developing countries and small island developing states. http://www.unohrlls.org/.
[22] R. Costanza, B. Fath, in: Ecological Economics. Encyclopedia of Ecology, 2nd edition, Elsevier, Oxford, 2019, pp. 258–264.
[23] F. Cottrell, Energy & Society: the Relation Between Energy, Social Change, and Economic Development, AuthorHouse, 2009.
[24] El Hamidi, F. (2016). Energy Subsidy Reform in Egypt: The Gender–'Energy' Poverty Nexus. *Economic Research Forum, Working Paper Series, No. 1055*. *Available at SSRN 3054085*.
[25] L. El-Katiri, The energy poverty nexus in the middle east and north Africa, OPEC Energy Rev. 38 (3) (2014) 296–322.
[26] J. Evans, S. Hyndman, S. Stewart-Brown, D. Smith, S. Petersen, An epidemiological study of the relative importance of damp housing in relation to adult health, J. Epidemiol. Community Health 54 (9) (2000) 677–686.
[27] M. González-Eguino, Energy poverty: an overview, Renew. Sustain. Energy Rev. 47 (2015) 377–385, doi:10.1016/j.rser.2015.03.013.
[28] K. Hadri, Testing for stationarity in heterogeneous panel data, Econ. J. 3 (2) (2000) 148–161.
[29] G.E. Halkos, N.G. Tzeremes, S.A. Kourtzidis, Regional sustainabilityefficiency index in Europe: an additive two-stage DEA approach, Oper. Res. 15 (1) (2015) 1–23.
[30] Halkos, G. (2017). Global energy and sustainable development: Introduction. *MPRA Paper No. 81967*. Online at https://mpra.ub.uni-muenchen.de/81967/.
[31] J. Healy, Housing, Fuel Poverty, and Health: A Pan-European Analysis, Ashgate Publishing, 2004.
[32] S.T. Herrero, Energy poverty indicators: a critical review of methods, Indoor Built Environ. 26 (7) (2017) 1018–1031.
[33] K.S. Im, M.H. Pesaran, Y. Shin, Testing for unit roots in heterogeneous panels, J. Econ. 115 (1) (2003) 53–74, doi:10.1016/S0304-4076(03)00092-7.
[34] S. Kahouli, An economic approach to the study of the relationship between housing hazards and health: the case of residential fuel poverty in France, Energy Econ. 85 (2020) 104592.
[35] K. Kaygusuz, Energy for sustainable development: a case of developing countries, Renew. Sustain. Energy Rev. 16 (2) (2012) 1116–1126, doi:10.1016/j.rser.2011.11.013.
[36] T. Kose, Energy poverty and health: the Turkish case. Energy sources, part B, Econ. Plan. Policy 14 (5) (2019) 201–213.
[37] T.H. Le, C.P. Nguyen, Is energy security a driver for economic growth? Evidence from a global sample, Energy Policy 129 (2019) 436–451.
[38] B. Legendre, O. Ricci, Measuring fuel poverty in France: which households are the most fuel vulnerable? Energy Econ. 49 (2015) 620–628.
[39] G. Legros, I. Havet, N. Bruce, S. Bonjour, K. Rijal, M. Takada, C. Dora, The energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa, World Health Organization, 2009.
[40] A. Levin, C.F. Lin, C.S.J. Chu, Unit root tests in panel data: asymptotic and finite-sample properties, J. Econ. 108 (1) (2002) 1–24, doi:10.1016/S0304-4076(01)00098-7.
[41] W. Li, F. Chien, C.C. Hsu, Y. Zhang, M.A. Nawaz, S. Iqbal, M. Mohsin, Nexus between energy poverty and energy efficiency: estimating the long-run dynamics, Resour. Policy 72 (2021) 102063.
[42] M. Llorca, A. Rodríguez-Álvarez, T. Jamasb, Objective vs. subjective fuel poverty and self-assessed health, Energy Econ. 87 (2020) 104736.
[43] O.M. Longe, A review of energy and gender poverty nexus in south Africa, in: 2020 IEEE PES/IAS Power Africa, IEEE, 2020, pp. 1–5.
[44] O.M. Longe, An Assessment of the energy poverty and gender nexus towards clean energy adoption in rural South Africa, Energies 14 (12) (2021) 3708.
[45] G.S. Maddala, S. Wu, A comparative study of unit root tests with panel data and a new simple test, Oxf. Bull. Econ. Stat. 61 (s1) (1999) 631–652, doi:10.1111/1468-0084.61.s1.13.
[46] B. Mainali, P. Shonali, N.D. Rao, S. Semida, Assessing rural energy sustainability in developing countries, Energy Sustain. Dev. 19 (2014) 15–28, doi:10.1016/j.esd.2014.01.008.
[47] Masud, J., Sharan, D., and Lohani, B.N. (2007). Energy for all: addressing the energy, environment, and poverty nexus in Asia. *Asian Development Bank Report*.
[48] A.M. McKinnon, Energy and society: herbert Spencer's 'energetic sociology' of social evolution and beyond, J. Class. Sociol. 10 (4) (2010) 439–455.
[49] L. Middlemiss, P. Ambrosio-Albala, N. Emmel, R. Gillard, J. Gilbertson, T. Hargreaves, et al., Energy poverty and social relations: a capabilities approach, Energy Res. Soc. Sci. 55 (2019) 227–235.
[50] G. Mohan, Young, poor, and sick: the public health threat of energy poverty for children in Ireland, Energy Res. Soc. Sci. 71 (2021).
[51] M. Moniruzzaman, R. Day, Gendered energy poverty and energy justice in rural Bangladesh, Energy Policy 144 (2020) 111554 111554, doi:10.1016/j.enpol.2020.
[52] R. Moore, Definitions of fuel poverty: implications for policy, Energy Policy 49 (2012) 19–26.
[53] C.P. Nguyen, M.A. Nasir, An inquiry into the nexus between energy poverty and income inequality in the light of global evidence, Energy Econ. 99 (2021) 105289.
[54] C.P. Nguyen, T.D. Su, T.D. Bui, V.T.B. Dang, B.Q. Nguyen, Financial development and energy poverty: global evidence, Environ. Sci. Pollut. Res. 28 (26) (2021) 35188–35225.
[55] P. Nussbaumer, Energy For Sustainable Development-An Assessment of the Energy-Poverty-Development Nexus, Universitat Autònoma de Barcelona, 2012.
[56] P. Nussbaumer, M. Bazilian, V. Modi, Measuring energy poverty: focusing on what matters, Renew. Sustain. Energy Rev. 16 (2012) 231–243.
[57] S. Oum, Energy poverty in the Lao PDR and its impacts on education and health, Energy Policy (2019) 132.
[58] S. Pachauri, D. Spreng, Measuring and monitoring energy poverty, Energy Policy 39 (12) (2011) 7497–7504.
[59] P. Pedroni, Full modified OLS for heterogeneous cointegrated panels, Adv. Econ. 15 (2000) 93–130.
[60] P. Action, *Poor people's energy outlook 2010*, Practical Action Publishing, 2010.
[61] C. Robinson, Energy poverty and gender in England: a spatial perspective, Geoforum 104 (2019) 222–233, doi:10.1016/j.geoforum.2019.05.001.
[62] A. Rodriguez-Alvarez, L. Orea, T. Jamasb, Fuel poverty and well-being:a consumer theory and stochastic frontier approach, Energy Policy 131 (2019) 22–32.
[63] E.A. Rosa, G.E. Machlis, K.M. Keating, Energy and society, Annu Rev. Soc. 14 (1) (1988) 149–172.
[64] D. Rosie, W.B. Gordon, S.B. Neil, Conceptualizing energy use and energy poverty using a capabilities framework, Energy Policy 93 (2016) 0301–4215 /& 2016, doi:10.1016/j.enpol.2016.03.019.
[65] A.C. Sadath, R.H. Acharya, Assessing the extent and intensity of energy poverty using multidimensional energy poverty index: empirical evidence from households in India, Energy Policy 102 (2017) 540–550.
[66] M. Skutsch, J. Clancy, Unravelling relationships in the energy-poverty-gender nexus, Transform. Power (2017) 61–89.
[67] S. Smith-Nonini, The debt/energy nexus behind Puerto Rico's long blackout: from fossil colonialism to new energy poverty, Latin Am. Perspect. 47 (3) (2020) 64–86.
[68] B.K. Sovacool, C. Cooper, M. Bazilian, K. Johnson, D. Zoppo, S. Clarke, H.A. Raza, What moves and works: broadening the consideration of energy poverty, Energy Policy 42 (2012) 715–719.
[69] B.K. Sovacool, The political economy of energy poverty: a review of key challenges, Energy Sustain. Dev. 16 (3) (2012) 272–282.
[70] B. Sudhakara. http://citeseerx.ist.psu.edu/viewdoc/similar.

[71] H. Thomson, C.J. Snell, C. Liddell, Fuel poverty in the European Union: a concept in need of definition? People Place Policy Online (2016) 5–24.
[72] H. Thomson, C. Snell, S. Bouzarovski, Health, well-being and energy poverty in Europe: a comparative study of 32 European countries, Int. J. Environ. Res. Public Health 14 (6) (2017) 584.
[73] A.M. Tod, P. Nelson, A.C. De Chavez, C. Homer, V. Powell-Hoyland, A. Stocks, Understanding influences and decisions of households with children with asthma regarding temperature and humidity in the home in winter: a qualitative study, BMJ Open 6 (1) (2016) 1–14.
[74] United Nations (2018). *Policy brief #2: Achieving universal access to clean and modern cooking fuels, technologies and services; Policy brief #10: Health and environment linkages - maximizing health benefits from the sustainable energy transition. Accelerating SDG7 achievement Policy briefs in support of the first SDG7 review at the UN high-level political forum 2018.*United Nations, 2018.
[75] UN-Energy (2010). Energy for a Sustainable Future: The Secretary-General's Advisory Group on Energy and Climate Change Summary Report and Recommendations (New York: UN, April 28, 2010). http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGECC%20summary%20report%5B1%5D.pdf.
[76] H. Welsch, P. Biermann, Energy affordability and subjective well-being: evidence for European countries, Energy J. 38 (3) (2017) 159–176.