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Published in:
Journal of International Development

DOI:
[10.1002/jid.3855](https://doi.org/10.1002/jid.3855)

Publication date:
2023

Document Version
Peer reviewed version

[Link to publication in Discovery Research Portal](#)

Citation for published version (APA):
Opoku, E. E. O., Dogah, K. E., Kufuor, N. K., & Acheampong, A. O. (2023). The importance of human development in combating energy poverty. *Journal of International Development*. Advance online publication. <https://doi.org/10.1002/jid.3855>

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The Importance of Human Development in Combating Energy Poverty

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The authors declare no conflict of interest

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Abstract

Theoretically, the impact of human development on energy poverty could occur through a number of channels, for instance, through improved social mobility and employability. In this study, we elaborate on these channels and examine how human development affects energy poverty in Africa, where access to electricity is a challenge for many. We proxy human development with scores on the human development index (HDI), human capital and education levels, and analyze panel data on 40 African countries from 2000 – 2018. Employing a battery of estimation methods (including the panel fixed effects method, the Driscoll-Kraay estimator, the Lewbel two-stage least squares and the Hausman-Taylor estimator), the results suggest that an increase in human development generally improves energy poverty. The results are largely robust to different indicators of energy poverty (i.e., total, rural and urban population access to electricity, access to clean fuels and technologies for cooking, renewable electricity output and electric power consumption). We further perform sub-sample analyses, splitting the full sample into sub-Saharan African, Low- and Lower Middle Income, low HDI and low access to electricity countries. Except in a few instances, the results of the sub-samples buttress those of the full sample. Our findings posit that policies that champion universal access to affordable, reliable, sustainable, and modern energy including electricity will need to align with adequate investment in human development to help alleviate energy poverty in Africa. Thus, for most developing world to deliver on SDG7, policies must incorporate SDG4 interventions to alleviate energy poverty.

Keywords: Energy poverty, access to electricity, clean energy, human development, human capital, education

JEL Codes: I26, I39, J24, O15; O55; Q4

1. Introduction

This study examines the role of human development on energy poverty improvement in the developing world. Although there have been several definitions of energy poverty, a very general one that encompasses all is the lack of access to modern energy (electricity) and clean cooking facilities (IEA, 2010; UNDP, 2018). On the other hand, human development refers to improved health, knowledge, and standard of living of people. The need to alleviate energy poverty is echoed by the Sustainable Development Goal (SDG) 7 of the United Nations (UN), which seeks to ensure “*access to affordable, reliable, sustainable and modern energy for all*” (UNDP, 2019). The benefits of modern energy are enormous and among others include; release of home production time for more productive work-related activities, enhancement of health (switching from polluting energy sources) and better delivery of medical services, improvement in the quality of education/schooling, enhancement of firm and worker productivity, creating of job opportunities and increased entertainment options (Barron & Torero, 2017; Dinkelman 2011; Grogan 2015).

Though the concept of energy poverty is relatively new, especially from the perspective of developing economies, the literature has surged in recent years, mostly investigating the causes and effects of energy poverty (see inter alia, Wang et al., 2015; Churchill and Smyth, 2020, Churchill et al., 2020). So far, most of these studies identified socioeconomic, health, and even environmentally harmful effects of energy poverty on society (Zhao et al., 2020; Saud, Danish & Chen, 2018, while others identified lack of employment, low income and government budget constraints as major causes of energy poverty (Jayasinghe, Selvanathan & Selvanathan, 2021; Nguyen & Nasir, 2021). A few studies have instead focused on eradication methods for energy poverty and suggested electrification (electricity access) programs and financial development as key approaches (Saud, Danish & Chen, 2018; Saud et al., 2019). For example, Nguyen et al. (2021) show that financial development can attenuate energy poverty. This is also supported by Koomson and Danquah (2021), who demonstrate that financial inclusion can help improve energy poverty in Ghana. However, in some instances, the findings are not conclusive, suggesting the need for further studies. For example, Pereira et al. (2010) documents mixed findings on the effectiveness of electrification (electricity access) programs on energy poverty improvement. For developing economies, of which most are also the world’s energy-poorest, the energy poverty condition is critical as it hampers both economic growth and social development and, thus, deserves further and more conclusive investigation to guide effective policy actions. The present study seeks to contribute to the gap in the energy poverty literature by repositioning the problem of energy poverty within the context and the contributions of social reform including human development interventions.

According to the United Nations Development Programme (UNDP), human development presents the route to sustainable economic development (UNDP, 2019). It is argued that improvement (i.e., an increase in education and/or improvement in human capital) in human development is critical for technological progress and social change (Opoku et al., 2022; Saud et al., 2023). For example, those with more education, are shown to be more productive (and are higher-income earners), responsible and innovative, leading to the creation of new ideas, improved ways of doing things and higher standard of living (UNESCO, 2010). Therefore, our study objective is to investigate the effect of human development on the improvement of energy poverty plights among African countries.

It is theoretically plausible to expect the impact of human development (i.e., health, education and income) on energy poverty (access to modern, clean and sustainable energy) to occur through several channels since both variables are multi-dimensional. For instance, human

development may affect energy poverty through improved social mobility and employability channels. With energy accessibility problem comes the challenge of ‘affordability’, which depends mainly on ‘economic ability’ or purchasing power (income). Through expansion in educational programs and opportunities, people can receive formal training, which will increase their chances of getting jobs and rising the income ladder as well as social mobility. As income rises, the energy-poor can demand and pay for modern energy. This is corroborated by Jayasinghe et al. (2021), who document that energy poverty tends to decrease as social mobility (the number of employed in a household) increases. Secondly, human development can affect energy poverty via the mechanism of the so-called “energy ladder” theory. This theory states that a rise in average household income levels often triggers the substitution away from traditional fuels (which often constitute negative effects of energy poverty) to modern and cleaner fuel sources (see Van der Kroon., 2013; Bekun, 2022; Quito et al., 2023). In other words, an increase in socioeconomic status of households via higher income is associated with a rise in the “energy ladder,” which can accelerate cleaner energy transition and thereby improves ‘clean-energy poverty’ (Saud, Chen, Danish & Haseeb, 2019). Thirdly, human development via education channel can positively improve energy poverty predicaments. Indeed, with education, people understand the need to move from “dirty” energy sources to clean and more sustainable sources, and in doing so, they contribute to sustainable development and improvement in energy poverty (Jayasinghe et al., 2021). It is noted that higher human capital (i.e., higher education or social cognitive ability) has a significant positive impact on environmental quality, and thus, reduction in education can seriously threaten carbon dioxide (CO₂) emission goals (see inter alia, Chankrajang & Muttarak, 2017). This is consistent with the mechanism of Environmental Kuznets-Curve (EKC) theory, which suggests that human capital development drives up income levels and causes people to demand cleaner and better energy (Saud, Chen & Haseeb, 2020). This boosts the transition to clean energy usage and curtail the harmful effects of air pollution and deforestation from using traditional biomass cooking fuels (firewood, charcoal, cow dung, crop residue). Thus, more education, higher income and better healthcare can significantly improve the quality of life and, in effect, empower people as agents who can demand and chart new paths toward reduction in energy poverty and its harmful effects.

Even more, similar to the Covid-19 pandemic, energy poverty continues to exploit the inequality in human development. The low-income households and those living in rural areas in developing countries are the most reliant on traditional or biomass fuels (Jayasinghe et al., 2021). Thus, they are the ‘clean-energy poorest’. Also, it is easily noticeable that even in the energy-poor regions (such as sub-Saharan Africa [SSA]), the most affected or vulnerable are also the least economically empowered. As observed by Castano-Rosa et al. (2020, page 8), *“it is important to note that these households (which experience reduction in energy poverty) are still living in monetary poverty and, as a result, continue to experience a slight energy poverty”*. In other words, even where there appears to be adequate energy supply, households at the bottom end of the income spectrum are unable to access energy as they are unable to afford even the barest minimum energy for consumption (see Castano-Rosa et al., 2020; Jayasinghe et al., 2021). However, through improvement in human capital channels, these households can be better placed economically to afford their minimum energy needs and improve energy poverty. Lastly, by increasing job opportunities and income for people, government revenue could rise through taxation and dividends. The government can invest in expanding electricity infrastructure and access to deprived areas and subsidize the cost of usage for the poor, thereby improving energy poverty.

Despite being one of the fastest-growing regions globally, Africa is the most energy-poverty stricken region. Africa has the least energy consumption and electricity access rate in the World (World Economic Forum [WEF], 2016). The access to electricity situation is worse in SSA, as most Northern African countries have almost complete access rates. Data from the World Development Indicators of the World Bank indicate that, for example, at the end of 2019, about 53% (amounting to approximately 517.5 million) of the population of SSA did not have access to electricity. This is, however, an improvement from the previous year, such as 2000 (74%), 2005 (71%), 2010 (66%) and 2015 (61%), but this progress is driven largely by only a few countries, in particular Tanzania, Kenya and Ethiopia. This means the vast majority still are without access to electricity. In fact, as of 2018, the total electrification rate of SSA was only 45%, and around 900 million were without access to clean cooking fuels (Africa Energy Outlook, 2019). In their report, the International Energy Agency (IEA) observed that the lack of access to clean cooking accounts for almost 490,000 household air pollution-related deaths per annum and continues to rise significantly in the region, thus requiring urgent policy action (IEA, 2020).

The present study adds to our understanding of the energy poverty-human development literature from the perspective of African countries and contributes to the literature along the following lines: First, given the fact that energy accessibility or penetration situation is heterogeneous across different parts of Africa, it is important that studies on energy poverty in developing countries take into account these differences in order to provide a fuller picture. This will ensure that policy suggestions are not in a “*one-size-fits-all*” manner without considering the country or region-specific peculiarities. Acheampong et al. (2021) emphasised that tackling energy poverty problems requires recognising the different contextual factors that are vastly dissimilar across countries. Thus, our study contributes to the literature by extending the scope along this line and provides insights beyond the mostly ‘overgeneralized’ extant studies which focus on a few countries or blocs on the African continent. To the best of our knowledge, this study is among the first to explore the energy poverty-human development nexus within the continent in a disaggregated manner.

Second, unlike the extant literature, which largely focuses on causes of energy poverty and its socioeconomic or environmental impacts (Churchill et al., 2020; Zhao et al., 2021; Churchill & Smyth, 2020; Nguyen & Nasir, 2021), this study takes a distinctive route which argues that energy poverty studies need to go beyond the ubiquitous “cause and effect” analysis. To be specific, energy poverty studies on developing regions like Africa need to shed more light on the mitigation strategies by highlighting what actions/areas policymakers should devote their attention to. It is common knowledge that for Africa and most developing economies, the challenge is, most often than not, a lack of accessibility, and even where accessibility is possible, there is an intermittency concern. Therefore, this study examines how an improvement in human development can improve energy poverty conditions and alleviate its concomitant effects on growth, health, climate, and the environment. Third, it is suggested in the literature that further studies on the relationship between energy accessibility and human development-related indicators, particularly within cross-country datasets, are needed to enhance a better understanding of the energy poverty landscape (Acheampong et al., 2021). Hence, our study took up this challenge to provide a comprehensive insight on the situation across the African continent, accounting for the differences in the levels of both human development and electricity access to ensure that policy decisions are more targeted based on the socioeconomic context of the different regions/countries in Africa.

Although there is no consensus on the definition of energy poverty, for a macro and cross-country level analysis, we follow in the spirit of several empirical studies (Acheampong et al., 2021; Nguyen & Nasir, 2021) and proxy energy poverty comprehensively to include four variables; access to electricity as a percentage of the total population, access to electricity as a percentage of the rural population, access to electricity as a percentage of urban population and access to clean fuels and technologies for cooking as a percentage of the total population. Increase and improvement in energy poverty are explained to connote reduced and increased access (to electricity and clean fuels and technologies), respectively. Human development is proxied with HDI, education and human capital, consistent with the literature. In fact, low income levels, high mortality rates, poor education and low standard of living are common human development concerns in developing countries, making HDI and its component relevant proxies. Our results generally show that an increase in human development improves energy poverty. Furthermore, the results indicate that an increase in human capital and education is associated with an increase in electric power consumption, thereby improving energy poverty. Therefore, our findings posit that policies that champion universal access to electricity need to align with adequate investment in human development to help alleviate energy poverty in developing countries. The rest of the paper is structured as follows. The empirical methodology and data are reported in Section 2, whereas results and discussion are presented in Section 3. Section 4 covers the conclusion.

2. Methodology and Data

2.1 Model Specification

We follow a number of empirical studies (Nguyen & Nasir, 2021; Nguyen, Su, Bui & Nguyen, 2021) and augment with our main variable(s) of interest to specify our baseline model as below;

$$EnergyPov_{i,t} = \delta_1 + \theta_i HumanDev_{i,t} + \partial_i Controls_{i,t} + \varepsilon_{it} \quad (1)$$

where i represents entities/countries, t time/years, and ε is the error term. δ_1 is the intercept term. θ_i and ∂_i are respectively the coefficients of the main explanatory and control variables to be estimated. *EnergyPov* is the dependent variable, and it represents energy poverty. Consistent with Acheampong, Erdiaw-Kwasie & Abunyewah (2021) and Nguyen & Nasir (2021), the following four variables are used as proxies for energy poverty: access to electricity as a percentage of the total population, access to electricity as a percentage of the rural population, access to electricity as a percentage of urban population and access to clean fuels and technologies for cooking as a percentage of the total population. An increase (reduction) in energy access signifies a reduction (increase) in energy poverty.

HumanDev is the main explanatory variable and can take on three different measures: human development index (HDI), education, and human capital index. HDI, which represents a holistic measure of human development, is a composite variable comprising three different variables; a long and healthy life (proxied by life expectancy), knowledge (proxied by mean years of schooling), and a decent standard of living (proxied by gross national income per capita) (UNDP, 2021). HDI is computed as the geometric mean of normalized indices for each of the three variables. In addition to the holistic human development measure, we disintegrate and also focus on the education dimension of HDI. This enables us to ascertain the knowledge acquisition effect of human development on the dependent variable, energy poverty. Education is computed based on mean years of schooling and expected years of schooling (UNDP, 2021). We also proxy human development with human capital. The human capital measure transcends education and considers the quality or returns to education (Feenstra et al., 2015). The human capital index is computed as the mean years of schooling and an assumed rate of return to

education (Feenstra et al., 2015). Considering that human development increases people's value, enables them to acquire knowledge, and prepares them to be employable to earn decent incomes, we expect increase in human development to improve energy poverty, thereby increasing access to electricity and other modern energy.

Controls is a vector of control variables, and following the extant literature (see Nguyen & Nasir, 2021; Nguyen et al., 2021; Saud, Haseeb, Chen & Li, 2023) they include; $GDP_{i,t}$, $Urban_{i,t}$, $Inflation_{i,t}$, $GovExp_{i,t}$, $FinDev_{i,t}$ and $Industry_{i,t}$. GDP proxies the level of economic development, and it is measured as real GDP per capita (in constant 2010 prices). $Urban$ represents urbanization, and it is measured as the urban population as a percentage of the total population. $Inflation$ is a proxy for changes in the general price level of goods and services, including electricity and other energy-related services. Inflation is measured as the growth rate of the GDP implicit deflator and shows the rate of price change in the economy. $GovExp$ represents government expenditure, and it is measured as general government final consumption expenditure as a percentage of GDP. $FinDev$ connotes financial development, and it is a proxy for the state of financial development in the sampled countries. Financial development is measured as domestic credit to private sector by banks as a percentage of GDP. $Industry$ represents the value-added of the industry as a percentage of GDP, and its measurement comprises value added in mining, manufacturing, construction, electricity, water, and gas. Value-added represents the net output of a sector after summing up all outputs and deducting intermediate inputs.

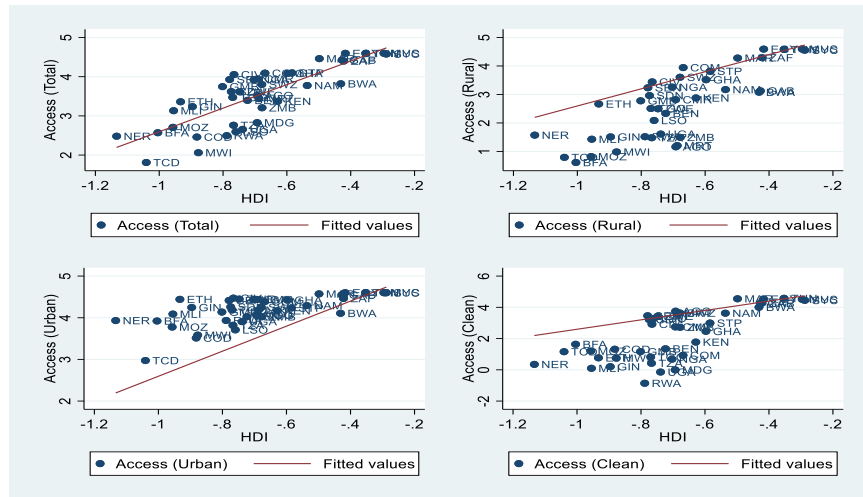
2.2 Data

The study is based on a yearly sample of 40 African countries over 2000-2018. For estimations using the human capital proxy, the number of countries reduces to 35 due to limited data. The sampled countries and years are chosen based on data availability for all the variables of interest. We obtain data on HDI and education from the UNDP and data on human capital from the Penn World Table (PWT 10.0). All other data are obtained from the World Development Indicators. We express all the variables in logarithmic form. Table 1 displays the summary statistics of the variables. While the mean value of HDI (0.5) is below the global average (for the period of the sample 2000-2018 of 0.7), the maximum value (0.8) is greater than the global average. Table 1 further shows that the mean access to electricity among the urban population is high (69.1%) relative to the total population (43.1%) and rural population (30.3%). However, some countries have complete access to electricity as depicted by the maximum value of access to electricity among the rural, urban and total population. On average, just about 26.6% of the population of the sampled countries have access to clean fuels and technologies for cooking. To a large extent, the table depicts that, on average, the sampled countries are energy poor.

Table 1: Summary Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
HDI	757	0.508	0.111	0.262	0.801
Human Capital	665	1.809	0.441	1.069	2.912
Education	757	4.828	2.161	1.100	10.200
Access to Electricity (Total)	756	43.121	28.600	1.270	100.000
Access to Electricity (Rural)	671	30.309	31.211	0.523	100.000
Access to Electricity (Urban)	756	69.082	21.690	10.085	100.000
Access to Clean Fuels	680	26.639	31.276	0.290	99.100
GDP	759	2269.235	2670.015	194.873	14417.060
Urbanization	760	39.503	16.261	14.610	89.370
Inflation	758	12.624	97.397	-18.075	2630.123
Government Expenditure	709	14.609	6.164	0.952	41.888
Financial Development	730	21.336	18.993	0.449	106.260
Industry	754	24.67553	10.50005	1.305321	72.12296

Figures 1-3 show the association between the energy poverty variables and the main explanatory variables. Generally, the figures indicate a positive association between the energy poverty variables and the main explanatory variables, preliminarily suggesting that increases in HDI, education and human capital are associated with a reduction in energy poverty. The association found in Figures 1-3 is only preliminary and not constructive as it does not account for the effect of other variables, and the methodology is not robust enough to be conclusive. In the next section, we describe more robust estimation methods to establish the relationship between the dependent and the explanatory variables.

**Figure 1: Relationship between the Energy Poverty and HDI**

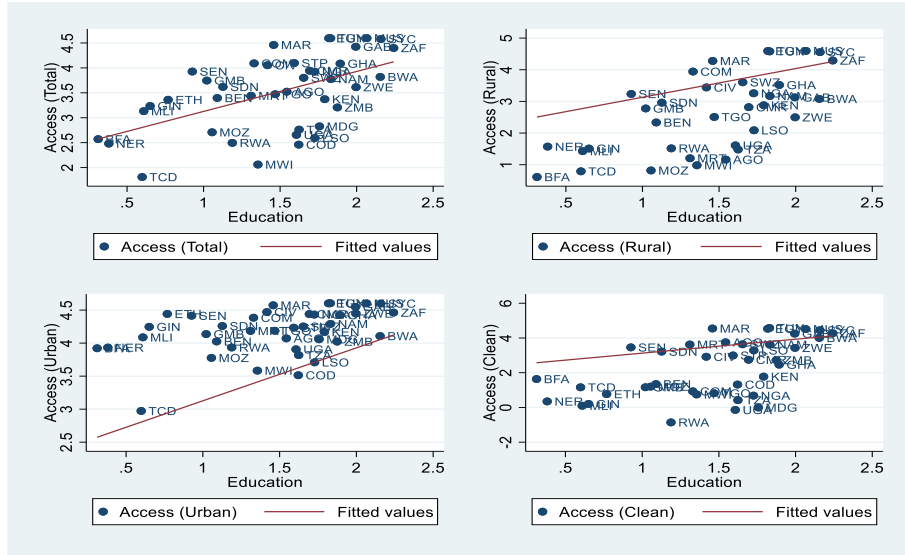


Figure 2: Relationship between the Energy Poverty and Education

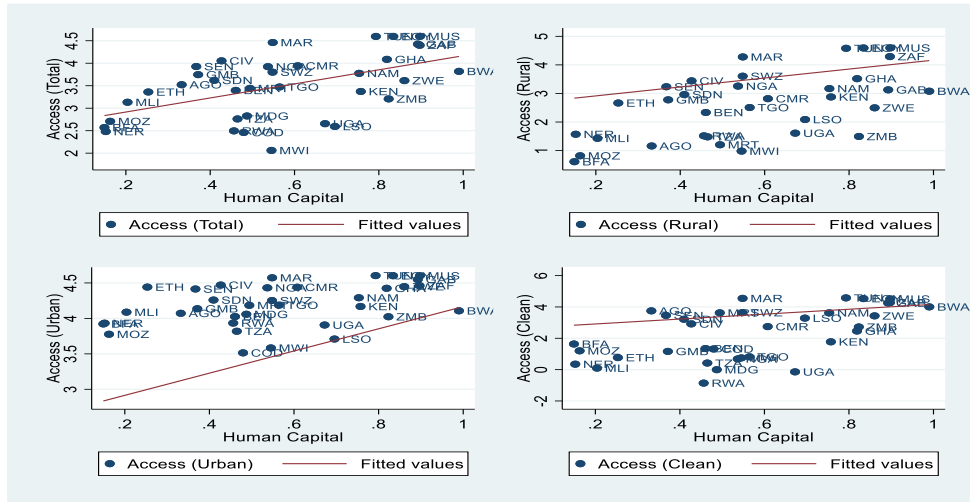


Figure 3: Relationship between the Energy Poverty and Human Capital

2.3 Estimation method

In many empirical studies as this, there are two major methodological hurdles to circumvent. The first deals with potential cross-sectional dependence (CSD). Panel data usually show substantial CSD in the errors. De Hoyos & Sarafidis (2006) indicate that this may be the case due to the presence of common shocks and unobserved components that are typically contained in the error term, spatial dependence, and idiosyncratic pairwise dependence in the disturbances with no distinct form of common components or spatial dependence. As a result, mistakenly ruling out cross-sectional correlation in the estimation of panel models can lead to direly biased statistical inferences (Hoechle, 2007). Following this, adjusting the standard errors of regression estimates for potential dependence of residuals when using panel data is an econometrically prudent way forward (Hoechle, 2007). Considering this, we employ the consistent Driscoll-Kraay estimator by Driscoll & Kraay (1998). The Driscoll-Kraay estimator produces heteroscedasticity and autocorrelation consistent standard errors that are robust to general forms of cross-sectional and temporal dependence (De Hoyos & Sarafidis, 2006; Hoechle, 2007).

The second methodological hurdle to overcome is dealing with potential endogeneity bias that may result from reverse causality and/or measurement error. To cater for this, we employ an instrumental variable estimation. The use of the instrumentation strategy follows the search and use of appropriate instruments to identify the model. These instruments must show considerable correlation with the potential endogenous variable(s), meet orthogonality conditions and must be duly eliminated from the model so that their impact on the outcome variable is only indirect (Bazzi & Clemens, 2013). A major practical drawback in using instrumental variable estimation is finding appropriate instrumental variables. It is largely argued that in many instances, these instrumental variables are either invalid, weak or both, and do not explain variation in the endogenous variable(s) much (Bazzi & Clemens, 2013; Bound et al. 1995). Employing these instruments could generate misleading conclusions (Durlauf et al., 2005). We employ the Lewbel (2012) two-stage least squares (2SLS) to circumvent the challenge of finding appropriate instruments.

The Lewbel 2SLS exploits heteroskedasticity for identification and does not rely on standard exclusion restrictions. This approach is often employed in the absence of external instruments or when external instruments are weak in standard instrumental variable estimations (Mishra & Smyth, 2015). The Lewbel 2SLS employs instruments generated within the model. The estimation follows two main stages; in the first stage, the endogenous variable (i.e. the main explanatory variable) is regressed on the exogenous variables, and the residuals are retrieved. The technique employs a heteroskedastic covariance restriction to build an internal instrument with heteroskedasticity as a precondition for identification. Lewbel (2012) argues that heteroscedasticity is more plausible than homoskedasticity in most applications. In the second stage, the estimated residuals are used to construct instruments to estimate the structural equation. The Lewbel 2SLS technique has widely been used in empirical studies (Arcand et al., 2015; Emran, & Hou, 2013; Millimet & Roy, 2016). We consider our main explanatory variable(s) the endogenous variable(s).

3. Results and Discussion

Prior to undertaking the main empirical estimations, we perform some preliminary analysis based on the fixed effect (FE) method. Undoubtedly, the FE method is a useful approach for examining the panel model at firsthand since it accounts for unobserved cross-section-specific heterogeneity. In all the FE estimations, we use the robust standard errors to tackle potential heteroscedasticity and autocorrelation.¹ The results show HDI having positive and statistically significant (1%-10% levels) coefficients in all the estimated models. Though the coefficients of human capital are generally positive, they are only statistically significant when the dependent variable is Rural Access. The results using education as the main explanatory variable are similar to those of the HDI, where all the coefficients are positive and statistically significant except where the dependent variable is Clean Fuels. Preliminarily, the results suggest that all other things being equal, whereas improvement in HDI and education are associated with an increase in access to electricity (for the rural, urban and entire population), improvement in human capital is only associated with an increase in rural access to electricity. Regarding the control variables, whereas the coefficients of urbanization and financial development are generally found to be positive (statistically significant), those of inflation, industry and GDP are largely statistically insignificant. The coefficient of government expenditure variable is generally negative and only highly statistically significant where human capital is the main explanatory variable.

Even though the FE method can accommodate potential heteroscedasticity and autocorrelation

¹ To conserve space we do not report these results. They can however be made available upon request.

issues, it cannot produce reliable estimates when CSD is present. Following this, in Table 2, we report results based on the Driscoll-Kraay estimator, which produces consistent standard errors even in the presence of heteroscedasticity, autocorrelation and CSD (De Hoyos & Sarafidi, 2006; Driscoll & Kraay, 1998). Table 2 reports 12 models; 1-4 for HDI, 5-8 for human capital and 9-12 for education. Similar to the FE estimations in Table A2, the coefficients of HDI are positive and statistically significant (1% level), except that the coefficient of HDI now becomes negative and slightly statistically significant where Clean Fuels is the dependent variable. Unlike the FE estimations, the coefficients of human capital are positive and statistically significant except where Urban Access is the dependent variable (Table 2). The results of the education variable (Table 2) are similar to those of HDI. The estimations based on the Driscoll-Kraay estimator suggest that *ceteris paribus*, improvement in HDI, human capital and education are generally associated with increased access to electricity (at the national, urban and rural levels).

The main difference between the FE and Driscoll-Kraay estimator results is the significance of the coefficients of the main explanatory variables in the estimations, where Clean Fuels is the dependent variable, which may be driven by the CSD ignored in the FE estimations. Regarding the control variables, the Driscoll-Kraay estimator shows more statistically significant coefficients. For example, the coefficients of GDP are now statistically significant and generally positive, suggesting that, all other things being equal, an increase in GDP is associated with an increase in access to electricity and clean fuels and technologies for cooking. Similarly, an increase in urbanization and financial development is associated with increased access to electricity and clean fuels and technologies for cooking. Whereas the industry results are not consistent, those of inflation and government expenditure are associated with decreasing access to electricity and clean fuels and technologies for cooking.

The Lewbel Two-Stage Least Squares (2SLS)

Even though the two estimators used afore (FE and Driscoll-Kraay) are robust to many econometric issues (such as heteroscedasticity, autocorrelation and CSD), they do not tackle a significant potential problem, that is, endogeneity that may occur as a result of reverse causality or measurement error. To cater to this, we employ the 2SLS due to Lewbel (2012). In implementing the Lewbel 2SLS, a significant precondition is the existence of heteroscedasticity in the errors of the first stage regression (Lewbel, 2012). To establish this, we run an OLS regression of the main explanatory variables (HDI, human capital and Education) on the exogenous (other independent) variables² and perform the Breusch-Pagan test for heteroscedasticity. The null hypothesis of homoscedasticity is rejected for all the estimated regressions (at least 5% significance level)³. Having established heteroscedasticity, we proceed to report and discuss the Lewbel 2SLS results.

Considering that the 2SLS estimations control endogeneity, we settle on these as our main results. Table 3 reports results using HDI as the main variable of interest. Consistent with the FE and Driscoll-Kraay results, the coefficient of HDI is generally positive and statistically significant in the estimations with access to electricity (total, rural and urban) as the dependent variables. However, in the estimation where Rural Access is the dependent variable, the coefficient of HDI turns statistically insignificant when GDP is controlled for. Also, where the dependent variable is Clean Fuels, the coefficient of HDI is positive and statistically significant when GDP is not controlled for, but negative when GDP is controlled for. The difference in

² We do this to represent the first stage/reduced form regression in the Lewbel 2SLS.

³ To conserve space, we do not report the results for these estimations.

the results may be explained by the fact that GDP is already included in the computation of HDI. Including both in the same estimation may suffer multicollinearity problems.⁴ As a result, in the case where HDI is the main explanatory variable, we focus on the estimations that do not control GDP's effect. Hence, the results indicate that *ceteris paribus*, increase in HDI is associated with increased access to electricity (at the national, urban and rural levels) and clean fuels and technologies for cooking. Specifically, a 1% increase in HDI is expected to be associated with an increase in access to electricity by about 2.2%, 5.7%, 1.0% at the national, rural and urban levels, respectively, and by about 1.9% increase in access to clean fuels and technologies for cooking. The positive role of HDI in improving energy poverty can be explained by the fact that improved HDI increases economic/job opportunities for people. With increased jobs and income, people can afford to access electricity hence improving energy poverty. Improvement in HDI also connotes enlightenment of people, facilitating the transition to more modern and clean energy from “dirty” sources of energy.

⁴ Correlation coefficient between HDI and GDP yields a coefficient of 0.82. With a rule of thumb of 0.8, this coefficient is an indication of high multicollinearity.

Table 2: Energy Poverty and Education (Driscoll-Kraay Estimator Results)

Dep. Vars.	Total Access	Rural Access	Urban Access	Clean Fuels	Total Access	Rural Access	Urban Access	Clean Fuels	Total Access	Rural Access	Urban Access	Clean Fuels
HDI	1.213*** (0.185)	2.970*** (0.363)	0.739*** (0.109)	-0.340* (0.177)								
Human Capital					0.224** (0.083)	0.929*** (0.162)	0.080 (0.048)	0.306* (0.163)				
Education									0.144** (0.055)	0.520*** (0.100)	0.078** (0.030)	-0.080 (0.076)
GDP	0.172*** (0.026)	0.315*** (0.092)	-0.013 (0.010)	0.912*** (0.075)	0.266*** (0.014)	0.458*** (0.051)	0.086*** (0.018)	0.838*** (0.156)	0.286*** (0.024)	0.568*** (0.076)	0.058*** (0.015)	0.888*** (0.085)
Urban	0.682*** (0.065)	0.296** (0.116)	0.233*** (0.027)	1.010*** (0.052)	0.718*** (0.068)	0.461*** (0.123)	0.208*** (0.020)	1.098*** (0.045)	0.771*** (0.074)	0.462*** (0.098)	0.289*** (0.029)	0.990*** (0.043)
Inflation	-0.057*** (0.018)	-0.110*** (0.028)	-0.031** (0.014)	0.035 (0.039)	-0.053** (0.018)	-0.088** (0.031)	-0.040*** (0.013)	0.026 (0.045)	-0.051** (0.019)	-0.113*** (0.030)	-0.026* (0.014)	0.038 (0.043)
Government	-0.166*** (0.025)	-0.357*** (0.077)	-0.009 (0.022)	0.355*** (0.097)	-0.355*** (0.028)	-0.699*** (0.075)	-0.168*** (0.032)	0.654*** (0.037)	-0.218*** (0.025)	-0.488*** (0.073)	-0.040* (0.023)	0.370*** (0.092)
Fin Dev	0.178*** (0.022)	0.271*** (0.052)	0.114*** (0.013)	0.292*** (0.063)	0.331*** (0.021)	0.651*** (0.062)	0.187*** (0.013)	0.136 (0.104)	0.282*** (0.018)	0.506*** (0.048)	0.179*** (0.010)	0.269*** (0.054)
Industry	-0.102*** (0.023)	-0.360*** (0.085)	-0.023 (0.034)	0.445** (0.181)	-0.070*** (0.013)	-0.207*** (0.061)	-0.049*** (0.012)	0.441 (0.301)	-0.146*** (0.025)	-0.464*** (0.113)	-0.050* (0.028)	0.461** (0.186)
Constant	1.001* (0.494)	2.880** (1.087)	3.779*** (0.279)	-11.370*** (0.339)	-0.815*** (0.270)	-2.051*** (0.648)	2.910*** (0.133)	-11.393*** (0.206)	-1.221*** (0.299)	-2.355*** (0.528)	2.411*** (0.196)	-10.804*** (0.155)
Observations	618	545	618	552	562	495	562	502	618	545	618	552
Countries	40	40	40	40	35	35	35	35	40	40	40	40
r2	0.799	0.705	0.594	0.740	0.826	0.689	0.645	0.732	0.779	0.674	0.561	0.739

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

Table 3: Energy Poverty and HDI (Lewbel 2SLS Estimator Results)

Dep. Vars.	Total Access	Total Access	Rural Access	Rural Access	Urban Access	Urban Access	Clean Fuels	Clean Fuels
HDI	2.151*** (0.262)	0.749* (0.384)	5.743*** (0.593)	0.508 (0.787)	0.954*** (0.182)	0.812** (0.332)	1.852*** (0.589)	-4.597*** (0.888)
Urban	0.655*** (0.071)	0.723*** (0.057)	0.087 (0.150)	0.432*** (0.111)	0.177*** (0.045)	0.227*** (0.036)	1.403*** (0.191)	1.391*** (0.131)
Inflation	-0.069*** (0.017)	-0.049*** (0.018)	-0.153*** (0.032)	-0.078** (0.034)	-0.038*** (0.013)	-0.032** (0.014)	0.046 (0.047)	0.113*** (0.043)
Government	-0.112** (0.044)	-0.186*** (0.051)	-0.227** (0.089)	-0.484*** (0.111)	-0.008 (0.032)	-0.006 (0.039)	0.619*** (0.117)	0.161 (0.170)
Fin Dev	0.108** (0.045)	0.226*** (0.047)	-0.065 (0.101)	0.549*** (0.114)	0.073*** (0.028)	0.106*** (0.035)	0.355*** (0.109)	0.736*** (0.130)
Industry	-0.056 (0.041)	-0.117*** (0.038)	-0.315*** (0.074)	-0.412*** (0.078)	-0.027 (0.025)	-0.021 (0.031)	0.773*** (0.213)	0.269* (0.146)
GDP		0.228*** (0.053)		0.646*** (0.114)		-0.022 (0.045)		1.424*** (0.115)
Constant	2.925*** (0.549)	0.081 (0.745)	8.369*** (1.178)	-2.051 (1.576)	4.163*** (0.371)	3.924*** (0.606)	-6.524*** (1.194)	-19.725*** (1.736)
Observations	618	618	545	545	618	618	552	552
Countries	40	40	40	40	40	40	40	40
r2	0.782	0.796	0.661	0.671	0.587	0.594	0.667	0.668

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$ **Table 4: Energy Poverty, Human Capital, and Education (Lewbel 2SLS Estimator Results)**

Dep. Var.	Total Access	Rural Access	Urban Access	Clean Fuels	Total Access	Rural Access	Urban Access	Clean Fuels
Human Capital	0.819*** (0.213)	2.691*** (0.453)	0.271** (0.136)	3.738*** (0.826)				
Education					0.082 (0.057)	0.585*** (0.132)	0.029 (0.047)	0.427*** (0.136)
GDP	0.185*** (0.043)	0.214** (0.102)	0.060** (0.025)	0.400*** (0.117)	0.300*** (0.029)	0.549*** (0.063)	0.069*** (0.022)	0.782*** (0.067)
Urban	0.725*** (0.051)	0.504*** (0.125)	0.210*** (0.026)	1.141*** (0.146)	0.779*** (0.050)	0.462*** (0.103)	0.295*** (0.032)	0.922*** (0.112)
Inflation	-0.072*** (0.015)	-0.147*** (0.037)	-0.046*** (0.010)	-0.092* (0.051)	-0.044** (0.019)	-0.118*** (0.034)	-0.021 (0.014)	-0.015 (0.038)
Government	-0.317*** (0.039)	-0.607*** (0.086)	-0.156*** (0.025)	0.866*** (0.120)	-0.218*** (0.047)	-0.485*** (0.096)	-0.041 (0.034)	0.370*** (0.135)
Fin Dev	0.286*** (0.031)	0.484*** (0.069)	0.172*** (0.020)	-0.135 (0.139)	0.292*** (0.029)	0.494*** (0.067)	0.186*** (0.018)	0.186*** (0.069)
Industry	-0.082** (0.036)	-0.272*** (0.084)	-0.053*** (0.019)	0.396 (0.307)	-0.144*** (0.037)	-0.469*** (0.077)	-0.048* (0.026)	0.448*** (0.170)
Constant	-0.502** (0.219)	-0.901 (0.557)	3.011*** (0.124)	-9.746*** (0.903)	-1.301*** (0.215)	-2.266*** (0.413)	2.348*** (0.153)	-10.169*** (0.521)
Observations	562	495	562	502	618	545	618	552
Countries	35	35	35	35	40	40	40	40
r2	0.807	0.630	0.635	0.605	0.778	0.674	0.559	0.726

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

Table 4 (Models 1-4) reports results using human capital as the main explanatory variable of interest. The coefficients of human capital are statistically significant and positive. The results suggest that, all other things being equal, an increase in human capital is associated with increased access to electricity and clean fuels and technologies for cooking. Specifically, 1% improvement in human capital is expected to be associated with an increase in access to electricity by about 0.8%, 2.7%, 0.3% at the national, rural and urban levels, respectively, and by about 3.7% increase in access to clean fuels and technologies for cooking *ceteris paribus*.

Regarding the education variable, the results reported in Table 4 (Models 5-8) indicate that the coefficient of education is positive in all the estimated models but statistically insignificant in the estimations with Total Access and Urban Access as the dependent variables. Specifically, a 1% increase in education is expected to be associated with an increase of 0.6% in access to electricity at the rural level and 0.4% in access to clean fuels and technologies for cooking at the national level. Like HDI, an increase in education increases opportunities for people to increase their incomes, get more enlightened to access electricity, and transition to modern and clean energy (Jayasinghe et al., 2021). The insignificant coefficient of education when Urban Access is the dependent variable implies that education does not explain access to electricity at the urban level. We believe that urban centres are more competitive and more developed relative to rural areas. HDI and human capital that transcends the definition of education are more important variables to consider. Human capital, for example, in its computation, includes the returns to education. So, in urban areas where lots of people are educated, greater returns and skills obtained from education become more important distinguishing factors than just obtaining an education. Also, with already high education levels in urban areas, further increase in education may yield minimal effect. The urban component of Total Access may also drive the results when Total Access is the dependent variable.

Regarding the control variables, urbanization is found to be generally positive and statistically significant in all the estimated models (Tables 3-4). Hence, an increase in urbanization is expected to be associated with increased access to electricity and clean fuels and technologies for cooking, all other things being equal. Although electricity and other amenities (such as water, healthcare and transportation) are generally low in African countries, they are much better in urban centres than in rural areas. Therefore, quite a several people migrate to urban centres to enjoy these amenities (Selod & Shilpi, 2021). Hence, generally, people get access to electricity when they move to the urban centres. Considering the fast pace of urbanization in many African countries, governments feel more pressure to supply electricity and other amenities in urban centres. Also, when people move to the urban centres, they can find well-paying jobs that increase their purchasing power and, hence, their ability to purchase modern and clean energy. Besides, coupled with the increase in income, living in urban centres comes with enlightenment that draws people away from using “dirty” energy in cooking to clean energy (fuels).

Increase in urbanization is also able to improve rural access to energy/electricity because many people migrate from rural areas resulting in less pressure on the remaining electricity resources for the relatively fewer remaining people, thereby improving energy poverty. The outcome of urbanization is consistent with other studies (Su, 2020). The financial development variable (Tables 3-4) is also found to generally have positive and statistically significant coefficients. Hence, all other things being equal, an increase in financial development is associated with increased access to electricity and clean fuels. Financial development is essential because it can increase the efficiency of a country’s financial system, which can boost economic activity and increase the demand for energy (Sadorsky, 2011). In recent years, the energy sector has

been attracting enormous foreign investments (Adom et al., 2019), and financial development is essential in channelling these investments into the African region (Sadorsky, 2011). Sadorsky (2011) notes that the effect of financial development on access to electricity can be divided into three; i) direct effect, where an improved financial development will afford consumers access to cheaper credit to purchase energy devices, ii) business effect, where improved financial development improves businesses' access to financial capital easily and less costly to spend on their energy exigencies, iii) wealth effect, where improved financial development resulting in increased stock market activities could cause individuals and businesses to increase their wealth and stand the position to increase their demand for energy services. The bottom-line of the essence of financial development is that it makes credit accessible and cheaper for energy expansion and consumption, and reduces financial risk (Ji & Zhang, 2019; Sadorsky, 2011). With this people move away from "dirty" energy sources that are detrimental to their health and the environment to clean energy.

Generally, the GDP variable shows positive coefficients (Tables 3-4). An increase in economic development reflected in an increase in GDP comes with opportunities that create jobs and increase people's incomes. With job opportunities and increasing incomes come increasing purchasing power, which makes people consume electricity and other clean and modern energy. As a result, with increasing GDP, energy poverty improves. The result is consistent with Opoku, Kufuor & Manu (2021) and Yoo & Kim (2006). As expected, the inflation variable generally shows negative and statistically significant coefficients, implying that an increase in inflation reduces access to electricity and clean energy, all other things being equal. Hence, an increase in inflation exacerbates energy poverty. This is quite intuitive, as increasing inflation increases the cost of electricity and hence reduces the purchasing power of consumers, thereby reducing access to especially people with low incomes. The result is consistent with Opoku, Kufuor & Manu (2021), and Sadorsky (2011). The results for the government expenditure variable is mixed; whereas it shows negative coefficients for access to electricity estimations, it shows positive coefficients for the clean fuels estimations. The results are counter-intuitive for the access to electricity estimations as one would expect an increase in government expenditure to increase access to electricity. That notwithstanding, it is imperative to mention that the effect of government expenditure on the economy is mixed and largely hinges on what governments spending priorities are (Barro 1991; Opoku & Yan, 2019). As the government expenditure variable used is general expenditure and not specifically expenditure on infrastructure or electricity, an increase in expenditure may be driven by say expenditures on national defence and security that may not affect access to electricity but rather reduce expenditure on electricity infrastructure.⁵ Also, Barro (1991) and Fischer (1991) emphasize how increasing government expenditure can adversely affect economic growth and other economic factors through distortions generated by taxation and crowding-out of private investment. An increase in taxation resulting from increased government expenditure will reduce people's real income and hence reduce their purchasing power.

The effect of the industry follows a similar trajectory as government expenditure; negative coefficients for the access to electricity estimations and positive coefficients for the clean fuels estimations. An increase in the industry is hence found to increase energy poverty by way of having a reducing effect on access to electricity. This could be explained by the fact that most industrial firms rely on the national grid for electricity and do not generate electricity. As a result, their activities compete with private consumers; the more industrial firms use electricity, the lesser access the populace have. However, an increase in industrial activities increases

⁵ We could not get data on government specific expenditures.

access to clean fuels and technologies for cooking. This may be explained by the technological and innovative advantages that may come with industrialization (Li & Lin, 2015; Shi, 2003), which shift countries from “dirty” to clean fuels.

Further Results

Considering that African countries are not at the same level of development and differ in so many other respects, we perform a sub-sampling analysis to ascertain whether there exists any difference across samples. Firstly, we restrict the sample to SSA and Low- and Lower-Middle Income Countries (LLMC) in the sample.⁶ The focus on SSA and LLMC follows the fact that the North African and Upper- and High Income (UHC) countries have high access to electricity) and these countries may drive the results.⁷ The results are based on the the Lewbel 2SLS and the HDI as the main explanatory variable. *(To conserve space we do not report these results. They can however be made available upon request)*. The results for both the SSA and LLMC sub-samples are qualitatively similar to those reported for the full sample in Table 3. For similar reasons given above, that GDP is already included in HDI computation, when we focus on estimations not controlling for GDP, increase in HDI is found to generally increase access to electricity at the national, rural and urban levels, all other things being equal. However, an increase in HDI is found to increase clean fuels only in the SSA sample.

Secondly, we restrict the sample based on the levels of HDI and access to electricity in the various countries of the sample. Thus, we focus on countries with low HDI and low access to electricity separately. We find a global average for the period of our sample (2000-2018) for HDI and access to electricity (using the total sample). For each country, we find the average over the same period. A country with an average value lower than the global average value is classified as low HDI and has equal or greater than the global average as a high HDI country. We do similarly for access to electricity.⁸ *(To conserve space we do not report these results. They can however be made available upon request)*. Again, the results for access to electricity in both sample groups are generally similar to those of the full sample (and also the SSA and LLMC samples), where an increase in HDI is associated with an increase in access to electricity at the national, rural and urban levels, all other things being equal. The results only differ slightly for the clean fuels estimations where, in our preferred models, the coefficient of HDI is not statistically significant in the low-HDI countries sample but is positive in the low electricity access sample. Generally, the sub-sample analyses indicate that the results are not driven by the sample, except in a few instances where clean fuels are the dependent variable for LLMC and low HDI countries samples. The results of the control variables for the sub-sample analyses are qualitatively similar to those of the full sample reported above.

⁶ For the SSA sample, we exclude the Northern African countries of Egypt, Morocco and Tunisia, and for the LLMC sample, High- and Upper-Income countries of Botswana, Gabon, Mauritius, Seychelles and South Africa are excluded. These classifications are based on the World Bank country classifications (<https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>)

⁷ The North African countries and UHC have almost 100% electricity access rate.

⁸ 3 countries (Mauritius, Seychelles and Tunisia) and 6 countries (Egypt, Gabon, Mauritius, Morocco, Seychelles, Tunisia) are found to be in the high HDI and high electricity groups respectively.

3.1 Robustness Checks

To ascertain whether the results are not driven by proxies used for the dependent variables and the methodology employed, we perform robustness checks of the results. Firstly, we employ two other measures for the dependent variables: renewable electricity output and electrical power consumption. The use of these variables is important for two reasons, i) SDG 7 of the UN emphasizes the use of renewable and clean energy as these are sustainable, ii) electrical power consumption enables us to ascertain how much energy (in kilowatt-hour [kWh]) is utilized beyond having access to the energy. We consider this essential because one can have access to electricity but have an inadequate amount of it (in kWh) to consume. *(To conserve space we do not report these results. They can however be made available upon request).*⁹ The results show that apart from the coefficients of HDI, which are statistically insignificant, the coefficients of the rest of the explanatory variables of interest (human capital and education) are positive and statistically significant. The results indicate that improvement in human development as reflected in increased human capital and education leads to the consumption of more renewable energy. With education, people understand the need to move from “dirty” energy sources to clean and more sustainable sources, and in doing that, they contribute to sustainable development. The UNDP (2019) notes that human development is the route to sustainable development. The results further indicate that increase in human capital and education is associated with an increase in electric power consumption. In essence, with the acquisition of human capital and education, consumption of electric power increases, reducing energy poverty.

We also make a case for the different sub-samples – SSA, LLMC, Low HDI Countries and Low Electricity Access Countries– using renewable electricity output and electric power consumption as the dependent variable. *(To conserve space we do not report these results. They can however be made available upon request).* The results for human capital and education are consistent with that reported for the full sample; that increase in human capital and education is associated with an increase in renewable electricity consumption. The coefficient of HDI is now found to be all statistically significant and positive, except in the SSA sample, which is negative. These results imply that, except for SSA, an increase in HDI is expected to increase renewable electricity output in all the sub-samples. This suggests that the full sample results, whereby the coefficients of HDI are statistically insignificant, may be driven by the inclusion of the Northern African countries. For the electric power consumption estimations, human capital and education are generally found to be positive and statistically significant in all the sub-samples. This indicates that an increase in education increases people’s electric power consumption, hence improving energy poverty. The HDI variable is largely found to be a statistically insignificant determinant of electric power consumption. In a nutshell, the analyses using renewable electricity output and electrical power consumption as dependent variables seem to be driven by the sample.

⁹ The variables are measured as renewable electricity output as a percentage of total electricity output, and electric power consumption (kWh per capita). To ensure consistency with other estimations these variables are logged. For the HDI estimations we do not include GDP for the same reasons stated afore. The 2SLS is used in the estimations.

To further ascertain the robustness of our results, we repeat all estimations using another method of estimation; the Hausman-Taylor estimator (Hausman and Taylor, 1981). The Hausman-Taylor estimator is an instrumental variable estimator that combines the consistency of the fixed-effect model with the efficiency and applicability of the random effect model (Baltagi et al., 2003) whiles controlling for endogeneity. We treat our main explanatory variables of interest (HDI, human capital and education) as endogenous variables in all the estimations.¹⁰ (*To conserve space we do not report these results. They can however be made available upon request*). Generally, the results generated by the Hausman-Taylor estimator are in line with those discussed afore, largely indicating that human development (HDI, human capital and education) improves energy poverty by increasing access to electricity.

4. Conclusion and policy recommendation

Energy poverty remains one of the major challenges that developing countries, especially African countries, are battling with. More than half of the population of Africa are energy poor, as they lack access to electricity and consume less electricity per capita relative to other regions of the world. The Sustainable Development Goal 7 seeks to ensure access to affordable, reliable, sustainable and modern energy for all, making sure that countries do not suffer energy poverty. There has also been a spurt in research on energy poverty in recent years. However, extant studies often focused on the determinants and effects of energy poverty without much bearing on eradication methods that could guide policy. The present study seeks to address this gap in the literature. The United Nations Development Programme (UNDP) suggests that human development presents the route to sustainable economic development (UNDP, 2019). For instance, improvement in health, education and standard of living are fundamental drivers of labour productivity, innovation and social change, which are associated with improved income. It follows then that human development may improve the ability to afford energy and understand the essence of using clean and renewable energy. We, therefore, posit that improved human development can help alleviate energy poverty through access to energy, responsible use of energy and contribution to energy technologies. In light of this, the key objective of the present study is to investigate the effect of human development on energy poverty.

The study analyses panel data on 40 African countries. We define energy poverty as the lack of access to modern energy (electricity) and clean technologies and fuels for cooking. Human development is defined as improved health, knowledge and standard of living and is proxied by Human Development Index (HDI), education and human capital. Panel fixed effects estimation method was used to control estimation bias associated with unobserved heterogeneity. The consistent Driscoll-Kraay estimator (Driscoll & Kraay, 1998) was used to produce heteroscedasticity and autocorrelation consistent standard errors that are robust to general forms of cross-sectional and temporal dependence. We also employ the Lewbel (2012) two-stage least squares (2SLS) and finally the Hausman-Taylor estimator (Hausman and Taylor, 1981), which control for endogeneity. We also conduct subsample analyses that partition the data into sub-Saharan African, Low- and Lower Middle Income, low HDI and low access to electricity countries. The results show that an increase in human development generally improves energy poverty. Apart from a few exceptions, the results are robust to a wide range of sub-sample analyses, various human development measures and energy poverty measures, and different estimation methods.

¹⁰ Since the estimation requires the inclusion of a time-invariant variable as part of the independent variables, we include country fixed effects in the estimations.

Our findings suggest that investment in human development is an effective means of reducing energy poverty, particularly in Africa with important implications for policy actions. Indeed, as low levels of income, high mortality rates, poor education and low standard of living are common human development concerns for countries in the developing world, our findings reveal that investments in human development and its components will help policymakers to deliver on the needed social change to improve livelihoods as well as alleviate the energy poverty plights. Improvement of human development is a matter of policy direction in number of developing countries, as the components of human development (such as health and education) are mainly government provisions to its populace. They usually come in the form of the provision of public infrastructure. This therefore calls for concerted policy action in developing countries, particularly African countries, to provide the requisite infrastructure to drive human development that will improve the lots of people. Hence, when governments and policymakers are able to provide and improve the quality of education and health, people will be able to improve their economic fortunes. With improvement in economic fortunes, accessibility of energy will be within the reach of people. This will help improve the energy poverty situation in developing countries. Additionally, since women and children (particularly of school going age) often bears the negative consequences from energy poverty plights, educational policies will need to be targeted at the minorities groups to ensure no one is left behind in the fight to improve energy access conditions across the developing world, which is also consistent with the United Nations' **SDGs Goals 7, 5 and 4**.

Like many empirical studies, our research is not without its limitations. The primary constraint we faced was the availability of data, which was particularly evident given the focus of our sample. As a result, our study was limited to a sample of 40 African countries between 2000 and 2018. Moving forward, we recommend conducting further studies that expand the sample size and duration to arrive at a more comprehensive conclusion. Analyses using micro-level data will also be helpful. Additionally, future research could explore a broader measurement of energy poverty beyond what is defined in this paper.

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