Environmental Science and Pollution Research (2023) 30:48721–48738
https://doi.org/10.1007/s11356-023-25997-4

REVIEW ARTICLE

Does energy poverty increases starvation? Evidence from sub-Saharan Africa

Thierry Messie Pondie[1] · Fon Dorothy Engwali[1] · Bruno Emmanuel Ongo Nkoa[1] · Edmond Noubissi Domguia[2]

Received: 17 September 2022 / Accepted: 14 February 2023 / Published online: 4 March 2023
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2023

Abstract
This study contributes to the existing literature on energy poverty and food security in sub-Saharan Africa (SSA). The study is conducted on a panel of 36 SSA countries over the period 2000 to 2020. Using several estimation methods, such as fixed effects, Driscoll-Kraay, Lewbel 2SLS, and the generalized method of moments, we find positive results for energy on food security. In SSA, the energy development index, access to electricity, and access to clean energy for cooking positively influence food security. This can encourage policy makers to prioritize investments in off-grid energy for vulnerable households through small-scale energy systems, which can promote food security by directly affecting local food production, preservation, and preparation, and contribute to human well-being and environmental conservation.

Keywords Driscoll-Kraay · Energy poverty · GMM · Lewbel 2SLS · Starvation · Sub-Saharan Africa

Introduction

Food security remains a major objective for economic policymakers in developing countries and is closely linked to social stability in these regions, where poverty can reach very high levels. According to FAO et al. (2022), nearly 720 million people worldwide were undernourished in 2020, 821 million people in 2017, and 784 million in 2015. This represents about 8.9% of the world's population, with an additional 10 million people in 1 year and nearly 60 million in 5 years, are at risk of hunger. The vast majority of these people live in developing countries, particularly in sub-Saharan Africa where Goal 2 of the Sustainable Development Goals (SDG) remains a priority (FAO et al. 2022). In addition, millions of people are still food unsecured. This situation is particularly acute in areas suffering from both monetary and non-monetary poverty. Two-thirds of these people live mainly in two regions of the world, namely sub-Saharan Africa and South Asia, with 237 million and 277 million hungry people respectively (Sustainable-Development-Goals 2021).

Moreover, the economic and social potential of these countries does not necessarily translate into improved food security. Indeed, they face a global economic context, characterized by fluctuations in growth, commodity prices, climate, trade, and the recent coronavirus pandemic and the Russian-Ukrainian war. Thus, these various factors have contributed to a further deterioration in the food security of the populations of sub-Saharan Africa. This alarming condition in SSA is undoubtedly linked to poor storage conditions and post-harvest losses, which are exacerbated by external supply problems. Thus, a major finding is that the prevalence of malnutrition remains high despite the continent's agricultural potential. To reverse this situation, recent literature has found that access to energy would be the royal road, as presented in the study by Candelise et al. (2021).

Responsible Editor: Ilhan Ozturk

✉ Thierry Messie Pondie
pondiethierry24@gmail.com

Fon Dorothy Engwali
denwali@yahoo.fr

Bruno Emmanuel Ongo Nkoa
ongoema@yahoo.fr

Edmond Noubissi Domguia
enoubissidomguia@yahoo.fr

[1] Dschang School of Economics and Management, Association Des Chercheurs en Economie Et Développement Appliqué (ACEDA), University of Dschang, Dschang, Cameroon

[2] Dynamic Young's Economic's (DYE), University of Dschang, Dschang, Cameroon

Access to energy is one way for sub-Saharan African countries to reverse these alarming trends in malnutrition. As one of the major goals, access to clean energy is central to achieving the other Sustainable Development Goals set since 2015. Thus, access to modern energy services is essential to meet basic social needs while promoting economic development. Modern energy services, including electricity, affect agricultural productivity, health, education, drinking water, and communication services (IEA 2014). Per capita energy availability and electricity consumption are closely correlated with economic development and other indicators of modern life, with the presumption that electricity consumption is related to better life and well-being (Sambodo and Novandra 2019; Starr 1972).

Among the existing challenges, new initiatives such as the link between energy and food security are being developed and/or implemented globally to promote well-being, which is essential for sustainable development (Howells et al. 2013). The Sustainable Development Goals (SDG) are a roadmap or guiding framework to achieve this (Keskinen et al. 2015). The Sustainable Development Goals, launched in 2015, address important issues at the heart of the link between energy and food security. These are "Ensure food security" (SDG-2) and "Ensure access to reliable, sustainable and modern energy services at affordable costs for all" (SDG-7). As rapid population growth, changing consumption patterns, economic growth, competition for land resources, and climate change increase the pressure on these resources, there is a need to address the links between energy and food security (Abulibdeh and Zaidan 2020). However, efforts to achieve SDGs 2 and 7 are increasingly undermined by a limited understanding of the current state of food and energy security.

Given the proven importance of energy to people, some countries have made huge progress in terms of access to electricity for their populations. But others are still lagging behind, such as South Asia and sub-Saharan Africa, with rates of 94.39% and 46.74% respectively, while Latin America and the Caribbean, East Asia and the Pacific, and the Middle East and North Africa show figures of 97.23%, 98.12%, and 98.42% access to electricity (IEA et al. 2020; World-Bank 2022). Given these statistics, it appears that most of the work done so far on the link between energy and food security has focused on the microlevel (Ahlborg and Sjöstedt 2015; Islam et al. 2017; Kirubi et al. 2009; Mushtaq et al. 2009). The present study goes beyond the previous studies by adopting a macroeconomic perspective in line with previous authors such as Sola et al. (2016), Nkiaka et al. (2021), Candelise et al. (2021), and Zakari et al. (2022). In addition, several theories have been developed to show the link between energy and food security. Based on various theories linking energy and food security, this link is subject to a non-consensual debate. Firstly, there is the sustainable livelihoods theory put forward by authors such as Chambers (1987) and Conway (1985). Secondly, there is Sen (1985) and Sen (1993) capability theory, which emphasizes the ability of each individual to take charge of his or her own environment. Finally, there is the right to food theory, which has been advocated since the work of Sen (1981) and continued by other works such as De Schutter (2010) and Burchi and De Muro (2012). These theories have underpinned much work on food security in relation to energy.

Therefore, this study departs from previous work and attempts to fill the gaps in the literature in at least five respects: first, it is one of the first studies to analyze the relationship between energy poverty and food security in the context of sub-Saharan Africa; a region that remains paradoxically rich in fertile land and energy resources. Second, in addition to using access to electricity and access to clean cooking energy as a measure of energy poverty reduction, we constructed an energy development index using the principal component analysis (PCA) method. Third, a food security index was constructed that is able to reflect the food situation in sub-Saharan Africa. Unlike other measures of food security, this index takes into account the four dimensions of food security as defined by the Food and Agriculture Organization of the United Nations (FAO), namely availability, accessibility, stability, and utilization. Fourth, the most robust estimation techniques were used to obtain better results (Lewbel 2SLS, Driscoll-Kraay and the generalized method of moments). Finally, fifthly, we studied the causal mediation of energy poverty reduction to food security in order to detect potential transmission channels using the structural equation technique.

The rest of the paper is organized as follows: the "Literature review: energy poverty and food security" section presents a brief review of the literature on the link between energy and food security. The model, data, and methodology are presented in the "Methodology and data" section. The "Empirical result and discussion" section presents the empirical results and discussion of the results. The "Conclusion and policy implications" section is devoted to the conclusion and policy implications.

Literature review: energy poverty and food security

The literature on the direct and indirect link between energy and food security, especially at the macrolevel, remains very limited. The interconnection between energy and food has been partially studied and explored in the literature. Nevertheless, a few works empirically assessing the link between these variables have yielded mixed results (Al-Maadid et al. 2017; Candelise et al. 2021; Taghizadeh-Hesary et al. 2019). Taghizadeh-Hesary et al. (2019) find, for example, a negative impact of energy price volatility (i.e., world oil and biofuel prices) on food prices. This in turn has a negative impact on food security, assuming that higher food prices would jeopardize food security and increase the number of undernourished people. In contrast, other studies show that electricity is needed for food production along the value chain: in crop production, fisheries, livestock, and forestry; in post-harvest processing (for example, many renewable energy technologies such as solar dryers and refrigerators can increase resource efficiency); and in addition, in food storage and processing; in food transport and distribution; and in food preparation (Edward et al. 2020; FAO 2012). In particular, improved access to electricity can improve food quality through cooking and refrigeration (World-Bank 2017).

The Practical Action (2013) report argues that rural electrification can support agricultural development, boosting productivity (e.g., by providing access to water pumping and irrigation), efficiency of crop conversion and storage, and agri-food products. The same report highlights several ways in which access to electricity can improve agricultural productivity. Electricity can provide mechanical power for soil preparation, planting, cultivation, irrigation, and harvesting, thereby increasing productivity and reducing the drudgery of farmers' work. Water availability is a key factor in determining irrigation potential, and electricity can facilitate water pumping. In off-grid rural areas, renewable energy technologies such as solar photovoltaic systems and wind pumps are technically and economically viable options for soil irrigation. Electricity also provides access to ICT, which in turn can help increase agricultural productivity by providing access to new farming methods through improved communications and knowledge sharing.

Therefore, the use of mobile phones could help to structure service providers for land cultivation. In addition to food storage and freezing, electricity facilitates food preservation (including smoking and forced air-drying) and processing into various high-quality and value-added forms (Candelise et al. 2021). In addition, access to electricity has an indirect impact on food security through multiple channels. For example, many studies have shown the role of energy on economic growth. This claim is also supported by theoretical and empirical macroeconomic studies, which consistently find improvements in food security in relation to economic growth (Soriano and Garrido 2016; Timmer 2000). Incomes rise and inequality falls as countries become richer through much improved access to energy. Other things being equal, this improvement helps create income-generating activities that can in turn improve food security. This contributes to increased household incomes, which in turn increases purchasing power, enabling households to access food (Smith and Haddad 2002; Tiwari and Zaman 2010).

The literature on income-generating activities also highlights how the use of electricity can help create small businesses, thereby stimulating production and helping existing businesses to become more efficient, thereby creating new jobs and income (Riva et al. 2018). For example, based on a study of nearly 4000 households in Indonesia, Gibson and Olivia (2010) show that improving the quality of electricity infrastructure has a positive effect on the growth of rural non-farm enterprises. These contribute to employment creation and livelihood diversification. As a result, better access to electricity is presented by Riva et al. (2018) as a factor that can promote income-generating activities for the population and impact food security. Similarly, Saing (2018) analyzes the effect of electrification on household consumption in Cambodia, using panel data from survey covering the period 2004–2011. He finds that household electrification in these areas has improved food security. As a result of rural electrification, household consumption increases by 16.6%, with households in the top quintile benefiting the most.

In the context of sub-Saharan Africa, some studies have been conducted to test the link between certain energy sources and food security. For example, Sola et al. (2016) based on a literature review found that electricity can impact food security in sub-Saharan Africa. Nkiaka et al. (2021) through spatial analysis found that energy security improves food security. Using Cobb–Douglas production functions based on the World Development Indicator data for 28 African countries, Zakari et al. (2022) find that promoting energy security promotes food security. This is possible because food production and distribution are energy-intensive activities. Energy is therefore fundamental to achieving food security and zero hunger. The availability, affordability, accessibility, and acceptability of energy can therefore help to address the growing shortage of agricultural production in Africa.

Three conclusions can be drawn from the non-exhaustive review of the literature. According to the literature, access to electricity and access to clean cooking energy have a direct and indirect effect on agriculture, both in rural and urban areas. Despite this, it is noted that very few studies have examined at the macrolevel the impact of energy poverty reduction on food security in sub-Saharan Africa. Moreover, the non-consensus findings in the literature deserve further investigation in a context still marked by food crises, exacerbated by Covid-19 and the Russia-Ukraine crisis. A developing region such as sub-Saharan Africa needs to assess the effects of energy poverty on food security in order to better implement policies that can significantly reduce the prevalence of malnutrition.

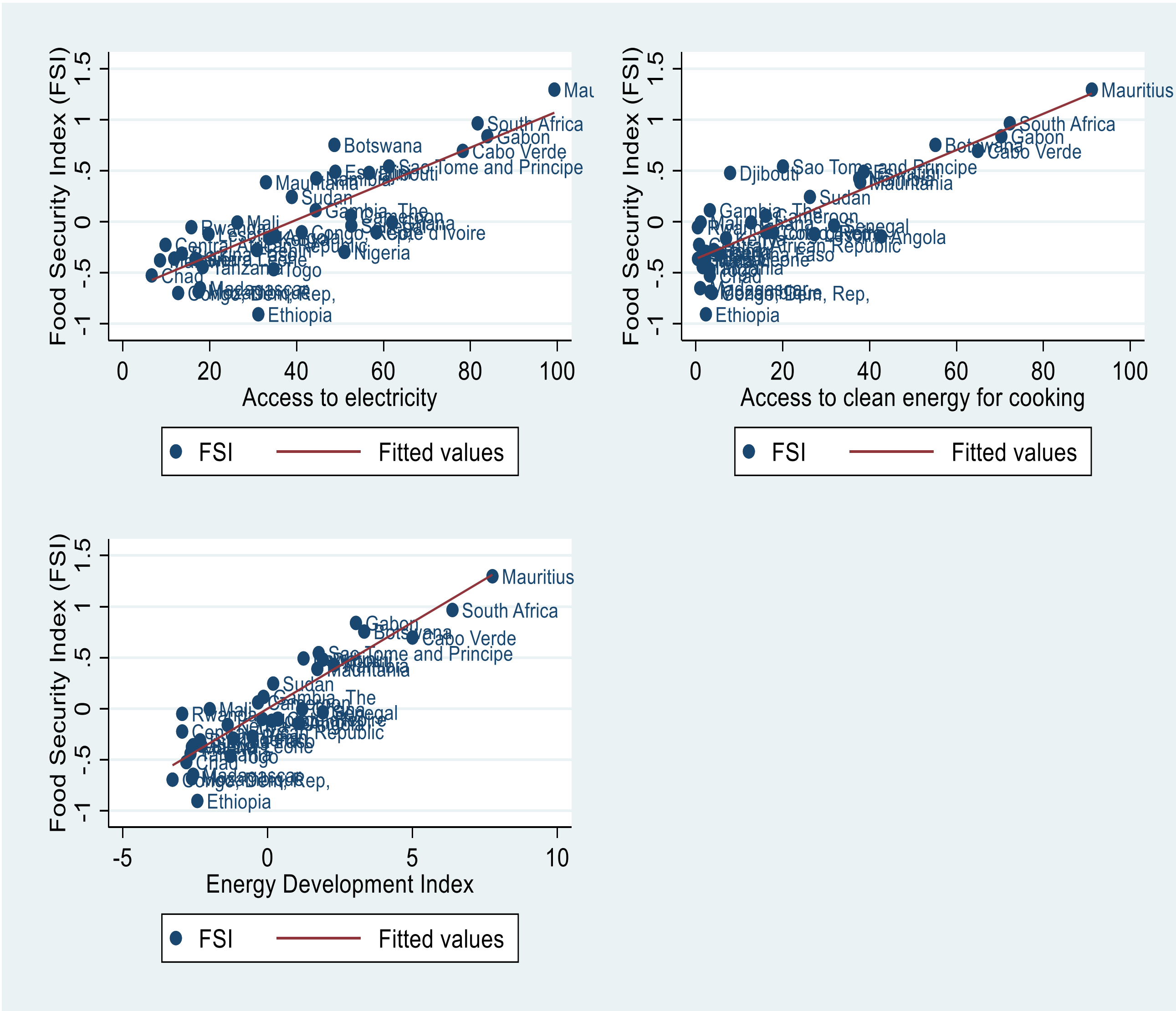

Fig. 1 Relation between energy and food security index. Source: authors

Methodology and data

Model and econometric estimation approach

Based on recent research for a range of developing countries, our model is inspired by Candelise et al. (2021). The model is therefore as follows:

$$y_{i,t} = \alpha_{i,t} + x_{i,t}\beta + +\mu_{i,t} + v_{i,t} + \varepsilon_{i,t} \quad (1)$$

where $y_{i,t}$ represents the dependent variables, α_i denotes country fixed effects, $x_{i,t}$ denotes independent variables, β denotes the coefficient estimate, $\varepsilon_{i,t}$ is the error term, i is the cross-sectional units, and t is the period. As our sample consists of several countries, there is a presumption of heterogeneity in our panel. Therefore, it is necessary to account for individual (country) heterogeneity. For this reason, we use the fixed effect model, which considers heterogeneity. By using fixed effects, we assume that each country has its own fixed effect. Errors are always homoscedastic, so specific effects are only taken into account at the residual level. Here is the empirical model:

$$FSI_{i,t} = \beta_0 + \beta_1 EP_{i,t} + \beta_2 X_{i,t} + \varepsilon_{i,t} \quad (2)$$

The food security index (FSI) measures food security, while the energy development index (EDI), access to electricity (Elec), and access to clean energy for cooking (Clean) measure energy poverty (EP). $X_{i,t}$ is the set of control variables and $\varepsilon_{i,t}$ is the error term.

$$FSI_{i,t} = \beta_0 + \beta_1 EDI_{i,t} + \beta_2 GDP/c_{i,t} + \beta_3 Fixe/T_{i,t} + \beta_4 EmplT_{i,t} + \beta_5 PopD_{i,t} + \beta_6 CTC_{i,t} + \beta_7 DCPS_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$FSI_{i,t} = \beta_0 + \beta_1 Elec_{i,t} + \beta_2 GDP/c_{i,t} + \beta_3 Fixe/T_{i,t} + \beta_4 EmplT_{i,t} + \beta_5 PopD_{i,t} + \beta_6 CTC_{i,t} + \beta_7 DCPS_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$FSI_{i,t} = \beta_0 + \beta_1 Clean_{i,t} + \beta_2 GDP/c_{i,t} + \beta_3 Fixe/T_{i,t} + \beta_4 EmplT_{i,t} + \beta_5 PopD_{i,t} + \beta_6 CTC_{i,t} + \beta_7 DCPS_{i,t} + \varepsilon_{i,t} \quad (5)$$

Fixed effect models allow for heterogeneity as a result of the country effect. A cross-sectional dependency is also present in the panel data. For this reason, we use the Driscoll and Kraay estimation method. It may not be true that our variables have a static relationship as assumed by the fixed effect model or Driscoll and Kraay. Although Driscoll and Kraay's fixed effects method is easy to implement, it does not account for unobserved heterogeneity. To address the question of endogeneity, we must either use the Lewbel 2SLS estimation method or rewrite our model dynamically. With Lewbel's technique, our results are more robust than when we use instrumental variables. Instrumental variable estimators are generally difficult to use in most applications due to the difficulty of finding suitable instruments that simultaneously satisfy these conditions (Baum et al. 2012; Lewbel 2012; Stock et al. 2002). As a solution to this problem, we use Lewbel's two-stage least squares (2SLS) which is applied when sources of identification, like appropriate internal and external instruments, are unavailable. In the absence of traditional identification information, Lewbel's 2SLS approach is essential for identifying structural parameters in regression models with an endogenous or poorly measured regressor. Instruments based on heteroskedasticity are constructed in-house for this method. Lewbel's 2SLS approach has the advantage of not requiring standard exclusion restrictions to be met (Lewbel 2012).

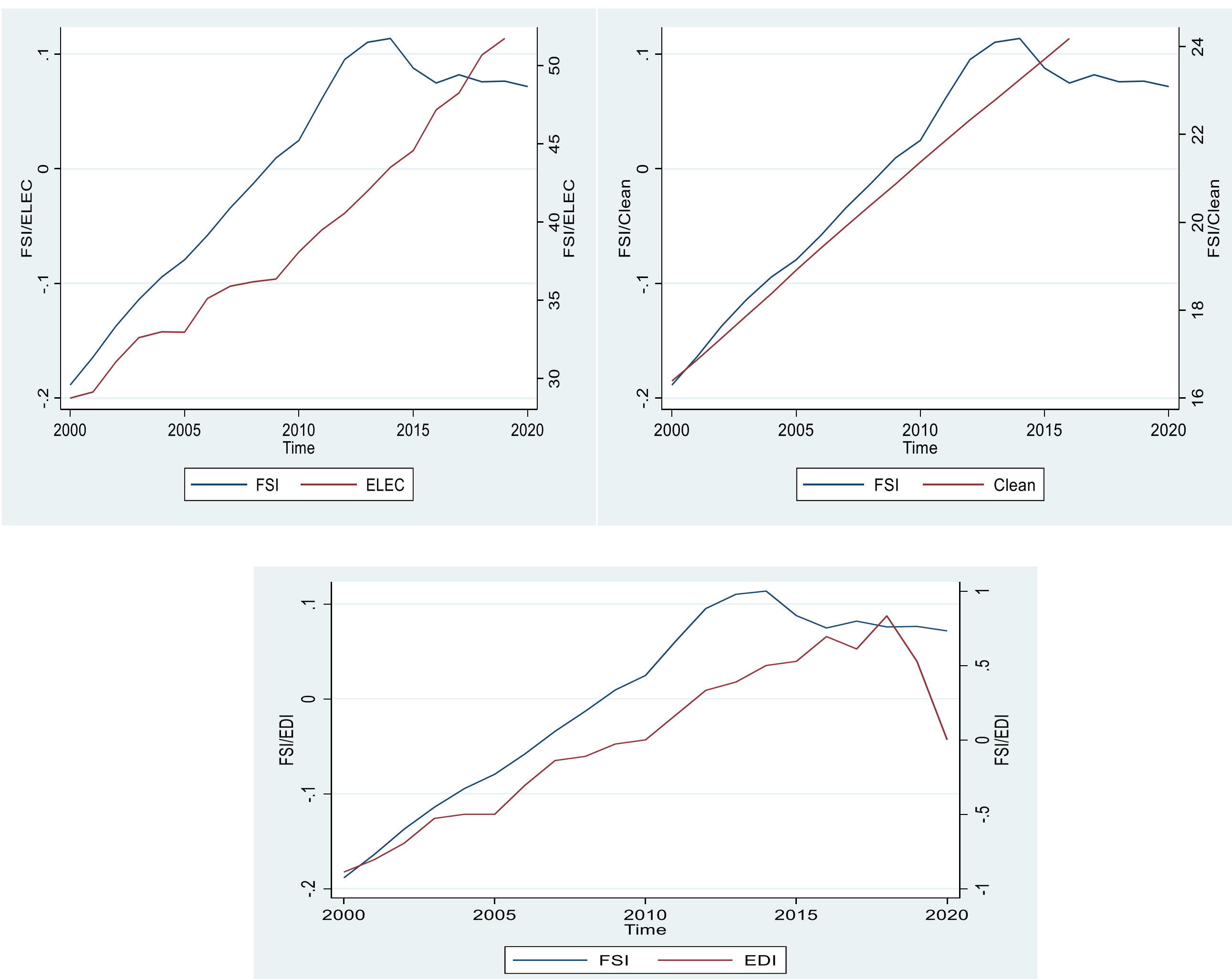

Fig. 2 Evolution of access to electricity and access to clean energy for cooking with food security. Source: authors

Accordingly, we apply a generalized method of moments (GMM), which was proposed by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998) so that the model's dynamics can also be verified. In a system, the generalized method of moments (GMM-S) is used for several reasons. Heteroskedasticity, endogeneity, overidentification, and validity are all econometric problems that are frequently solved with the GMM-S method. The GMM-S method is more efficient at dealing with heteroskedasticity in empirical studies, according to Baum et al. (2012). The related literature uses GMM to assess instrument strength, according to Bazzi and Clemens (2013). The dynamic panel GMM, according to Roodman (2009), can lead to too many instrument problems. The rule of thumb is that the number of instruments should be smaller than the number of countries in order to solve this problem. In addition, the GMM has the advantage of treating all explanatory variables as instrumental variables according to their lagged values (in terms of level and first difference). Hence, the model is as follows:

$$FSI_{i,t} = \beta_0 + \beta_1 FSI_{i,t-1} + \beta_2 EP_{i,t} + \beta_3 GDP/c_{i,t} + \beta_4 Fixe/T_{i,t} + \beta_5 EmplT_{i,t} + \beta_6 PopD_{i,t} + \beta_7 CTC_{i,t} + \beta_8 DCPS_{i,t} + \varepsilon_{i,t} \quad (6)$$

In addition, in this paper, energy poverty and food security are examined using a two-stage GMM system.

Data source

We use 36 sub-Saharan African countries from 2000 to 2020. The empirical estimates use indicators of access to energy indicators, food security, and other control variables. The empirical estimations are based on the availability of our variables of interest and dependent variables, as well as other control variables. Definitions and sources of our key variables are provided in Table 8 in the Appendix. Principal component analysis (PCA) is used to construct the food security index. To better understand the food situation in sub-Saharan Africa, sixteen variables were used to construct this index, taking into account the four dimensions of food security. FAOSTAT (2022) provides all of these variables. The variables used to measure energy poverty are access to electricity, access to clean energy for cooking, and an energy development index that was constructed based on the data taken from the World Development Indicator. As for the control variables, they are presented in detail in the Annex (Table 8). These are also taken from the WorldDevelopment Indicators.

Figure 1 shows a positive correlation between access to electricity, access to clean cooking energy, and the energy development index and the food security index.

Dependent variable

To measure the dependent variable, a composite index is constructed using principal component analysis (PCA) (Slimane et al. 2016). There are four dimensions to consider availability, accessibility, use, and stability. By transforming correlated variables into uncorrelated variables, the PCA[1] method aims to reduce the number of indicators.

Variables of interest

Acharya and Sadath (2019) and Thomson et al. (2016) understand energy poverty as a lack of access and use of modern energy services. Thus, this concept has been understood differently in the literature since the work of Boardman (1991). More recently, Churchill and Smyth (2021) refer to energy poverty as the impact of a lack of adequate access to energy on the objective or subjective well-being of a household. A household's subjective well-being is reduced by energy deprivation and poor cooking and heating conditions. This may capture the utility of energy access for a household, but is often plagued by self-reporting bias and survey inconsistencies (Herrero 2017).

Conversely, the proportion of households that spend a high proportion of their income on energy bills, which makes them more economically vulnerable, can measure energy poverty objectively. This is particularly the specific case in developing countries such as sub-Saharan Africa (Healy and Clinch 2004; Hills 2012; Tod and Thomson 2016). Nevertheless, these measures may suffer from sample selection bias, leading to over- or underestimation of energy poverty rates (Herrero 2017). The IEA (2010) and Banerjee et al. (2021) constructed an energy development index (EDI) using geometric and arithmetic means, while we use principal component analysis. This index is based on three indicators covering the renewable energy sector. These three indicators are (1) access to electricity; (2) consumption of renewable energy; and (3) access to clean energy for cooking. Thus, energy poverty reduction in this study is approximated by the energy development index, access to electricity, and access to clean cooking energy.

Figure 2 shows similar trends between the energy indicator and the food security index. This shows that access to electricity, access to clean cooking energy, and the energy development index have a positive impact on food security.

[1] All the variables used here are set out in the **Annex.

Table 1 Descriptive statistics

Variable	Abrev	Obs	Mean	Std. Dev	Min	Max	Data
Food security index	*FSI*	*756*	*−3.97E-05*	*0.5414625*	*−1.47*	*1.64*	FAOSTAT (2022)
Energy development index	*EDI*	*756*	*0.0000397*	*0.0292986*	*−0.04*	*0.09*	*WDI (2022)*
Access to electricity	*Elec*	*698*	*39.10533*	*24.86226*	*1.27018*	*100*	*WDI (2022)*
Access to clean energy for cooking	*clean*	*612*	*20.34379*	*24.47314*	*0.15*	*93.34*	*WDI (2022)*
GDP per capita	*GDP/c*	*739*	*1.739847*	*4.568149*	*−36.55692*	*28.676*	*WDI (2022)*
Fixed telephone	*Fixed/T*	*726*	*4.258437*	*9.935925*	*0*	*59.98999*	*WDI (2022)*
Employers total	*EmplT*	*720*	*1.991056*	*1.57211*	*0.04*	*8.39*	*WDI (2022)*
Population density	*PopD*	*756*	*86.79749*	*118.8185*	*2.17977*	*623.5172*	*WDI (2022)*
Control of corruption	*CTC*	*720*	*34.42657*	*21.96376*	*0.5050505*	*84.84849*	*WGI (2022)*
Domestic credit to private sector	*DCPS*	*723*	*20.11717*	*18.24886*	*0.449183*	*106.2603*	*WDI (2022)*

Source: authors

Table 2 The correlation matrix

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
(1)FSI	*1.000*									
(2)EDI	*0.588*	*1.000*								
(3)Elec	*0.403*	*0.892*	*1.000*							
(4)Clean	*0.260*	*0.937*	*0.793*	*1.000*						
(5)GDP	*0.011*	*0.010*	*-0.023*	*0.010*	*1.000*					
(6)Fixe/T	*0.213*	*0.218*	*0.061*	*0.224*	*-0.016*	*1.000*				
(7)EmplT	*0.392*	*0.527*	*0.419*	*0.509*	*0.042*	*0.210*	*1.000*			
(8)PopD	*0.320*	*0.291*	*0.334*	*0.231*	*0.116*	*-0.112*	*-0.066*	*1.000*		
(9)CTC	*0.503*	*0.541*	*0.362*	*0.482*	*0.089*	*0.078*	*0.292*	*0.340*	*1.000*	
(10)DCPS	*0.683*	*0.777*	*0.670*	*0.710*	*0.034*	*0.090*	*0.502*	*0.462*	*0.583*	*1.000*

Source: authors.

Control variables

Gross domestic product (GPD) per capita can positively influence food security at the level of a country or a larger region such as SSA (Campi et al. 2021; Candelise et al. 2021; Domguia et al. 2022). Information and communication technologies have positive effects on food security, particularly with fixed-line telephones (Fixed-T) as demonstrated by Anser et al. (2021). Employment (EmplT) also influences the degree of household food security (McCordic et al. 2021). Population density (PopD) affects the ability of a region to better feed its population (Badami and Ramankutty 2015; Vijay and Armsworth 2021).

Descriptive statistics (Table 1) show small biases. It is generally accepted that small fluctuations in the data lead to unbiased results. The correlation matrix (Table 2) shows low interdependence, indicating that there is no multicollinearity problem between the dependent and explanatory variables. It increases the availability of credit and enables agricultural entrepreneurs to access financial resources that can enable them to invest more in the agricultural sector (Chisasa and Makina 2012).

Empirical result and discussion

Here are the results of the base model. For this first estimation, fixed effects were used. Then, we use the Driscoll and Kraay (1998) and Lewbel (2012) technique to test our results.

Results and interpretation

For all our variables of interest, the results of the basic model are positive and significant. Thus, access to electricity, clean energy for cooking, and the energy development index all contribute to food security in sub-Saharan Africa, an increase of one unit in the energy development index, access to electricity and access to clean cooking energy contributes to improved food security in SSA. Thus, in terms of the estimated fixed effect, there is an increase of 10.83 units, 5.88 units and 1.68 units respectively. For the Driscoll-Kraay technique, there is an increase of 16.03 units, 1.37 units and 1.78 units respectively. For the Lewbel 2SLS technique, the increases are 15.91 units, 1.153 units and 1.70 units. These different improvements in food security are possible thanks to an improvement in the energy indicators. Moreover, the energy development index also remains positive and significant for all three methods used.

They suffer particularly from nutritional deficiencies and post-harvest losses. In sub-Saharan Africa, post-harvest food losses are significant in terms of both quantity and quality. A study conducted by FAO et al. (2018) in Uganda concluded that 3.3 unit of quantitative losses of maize occur at harvest and 10 unit during storage. During storage, qualitative losses were estimated at 50%. In recent years, farmers have experienced significant losses due to lack of access to electricity at harvest time (Ponguane 2021). Based on our observation, the control variables have a variety of effects on food security. Food security is positively impacted by gross domestic product per capita, ICT (fixed telephone), and employment. Anser et al. (2021), McCordic et al. (2021), Campi et al. (2021), and Candelise et al. (2021) have previously found similar results.

Regarding the fixed, Driscoll-Kraay, and Lewbel effects, financial development and population density are generally positive and significant. With this somewhat divergent result, one can observe a certain feverishness regarding financial development, which is still embryonic in order to really affect people's living standards. According to Chisasa and Makina (2012), financial development plays an important role in reducing food insecurity. Many sub-Saharan African countries have high population densities relative to food availability, which negatively affects food security. It is consistent with the findings of Badami and Ramankutty (2015) and Vijay and Armsworth (2021) that population density reduces food security in developing countries. Governance also plays a major role in a population's ability to access food. Previous studies have found that governance is able to influence food security positively or negatively, depending on whether one is in a country with or without high levels of corruption (Anser et al. 2021). In our case, the control of corruption, for example, turns out to have a significant negative impact depending on the techniques used. Nevertheless, it seems important to improve the level of governance in order to be able to redistribute wealth, for example to reduce inequalities and thus facilitate the availability and accessibility of food.

Eliminating food losses increases the availability of food, which may reduce the need to additionally supplement the amount available through transfer programs (at household level) or through commercial imports or food aid donations (at national level). The increase in food quantity, under normal conditions, should also lead to a reduction in prices for buyers, thus improving overall access to food. It is no coincidence that the renewed interest in price reduction has emerged with the global food price peaks of recent years. Maintaining lower quality products, which are currently most likely to be lost, can excessively benefit the poor when price reductions of lower quality foods are combined (Kadjo et al., 2016). With the availability and accessibility of energy, mainly from renewable sources, a large part of sub-Saharan Africa is able to improve their daily lives in terms of nutrition. This can be done through the acquisition of refrigerators, electric dryers, and other food preservation equipment. It would therefore seem necessary for states to invest more resources in the various sectors linked to energy, by facilitating the acquisition of solar panels and access to off-grid electricity.

Robustness check

We test the robustness or stability of our results in three ways. Firstly, we introduce additional control variables into our basic model, secondly, we homogenize our panel by taking into account the area of residence (urban and rural), and thirdly, we check the dynamic character of our model.

Additional control variables

Increasing the number of additional control variables does not change the results, especially with regard to the sign of our variables of interest. Certainly, the impact of the energy poverty index, access to electricity, and access to clean energy remains positive and significant on food security. However, we find that our additional variables (Table 3), such as imports, contribute positively and significantly to increasing the level of food security. This is also the case in Table 4, where new variables such as urbanisation and political stability are introduced. Thus, SSA countries rely on external food products to satisfy a good part of their internal nutritional demand. This result is similar to that found by Candelise et al. (2021) for developing countries. Consistent with the same study, urbanization is found to have a significant positive impact on food security in sub-Saharan Africa. Political stability ensures a certain degree of tranquility in agricultural activities, which helps to increase the amount of food stocks over time (Ribeiro et al. 2021).

Table 3 Baseline result

Variables	Food security index								
	Fixed effects						Driscoll-Kraay		
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
EDI	***0.1172****	***0.1083****					***0.1607****	***0.1603****	
	(0.479)	*(0.626)*					*(0.185)*	*(0.411)*	
Elec			***0.0966****	***0.0588****					***0.0170****
			(0.0731)	*(0.0992)*					*(0.0138)*
Clean					***0.0225****	***0.0168****			
					(0.0129)	*(0.0137)*			
GDP	*−0.0982*	*0.0013*	*0.0165*	*0.00236*	*0.0242***	*0.0329****	*−0.0401*	*−0.0249*	*−0.0877*
	(0.0123)	*(0.0028)*	*(0.0164)*	*(0.0155)*	*(0.0109)*	*(0.0101)*	*(0.0268)*	*(0.0227)*	*(0.0259)*
Fixed-T		*0.0419*		*0.0143***		*0.0212****		*0.0223****	
		(0.0505)		*(0.0607)*		*(0.0446)*		*(0.0639)*	
EmplT		*−0.0963*		*−0.0258***		*−0.0598*		*−0.0286****	
		(0.0100)		*(0.0120)*		*(0.0873)*		*(0.0538)*	
PopD		*−0.0650*		*0.0298*		*0.0181****		*0.0213***	
		(0.0440)		*(0.0559)*		*(0.0413)*		*(0.0521)*	
CTC		*−0.0859*		*−0.0902*		*−0.0973*		*0.0107***	
		(0.0821)		*(0.0998)*		*(0.0689)*		*(0.0429)*	
DCPS		*0.0739****		*0.0840****		*0.0642****		*−0.0273*	
		(0.0105)		*(0.0132)*		*(0.0924)*		*(0.0696)*	
Constant	*−0.0511*	*−0.0629*	*−0.384****	*−0.394****	*−0.503****	*−0.696****	*0.0157*	*0.0306*	*−0.663****
	(0.0572)	*(0.0506)*	*(0.0294)*	*(0.0597)*	*(0.0273)*	*(0.0508)*	*(0.0112)*	*(0.0222)*	*(0.0352)*
Observations	*739*	*630*	*682*	*618*	*595*	*540*	*739*	*630*	*682*
R-squared	*0.461*	*0.480*	*0.213*	*0.253*	*0.355*	*0.500*	*0.768*	*0.790*	*0.591*
Number of id	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*
F	*299.3*	*77.38*	*87.40*	*27.77*	*153.5*	*70.92*	*5616*	*7402*	*101.0*

Variables	Food security index								
	Driscoll-Kraay			Lewbel (2012) 2SLS internal and external					
	10	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
EDI				***0.1210****	***0.1591****				
				(2.008)	*(1.905)*				
Elec	***0.0137****					***0.0170****	***0.0153****		
	(0.0122)					*(0.0877)*	*(0.0128)*		
Clean		***0.0202****	***0.0178****					***0.0210****	***0.0170****
		(0.0311)	*(0.0317)*					*(0.0857)*	*(0.0147)*
GDP	*−0.0173*	*−0.0196*	*−0.0242*	*−0.0289*	*−0.0656*	*−0.0107*	*0.0133*	*0.0487*	*0.0487*
	(0.0236)	*(0.0267)*	*(0.0373)*	*(0.0237)*	*(0.0257)*	*(0.0346)*	*(0.0314)*	*(0.0265)*	*(0.0276)*
Fixed-T	*0.0883****		*0.0325****		*0.0214**		*0.0863****		*0.0356****
	(0.0107)		*(0.0586)*		*(0.0122)*		*(0.0130)*		*(0.0130)*
EmplT	*−0.0151**		*−0.0269****		*−0.0305****		*−0.0197**		*−0.0254***
	(0.0770)		*(0.0393)*		*(0.0105)*		*(0.0105)*		*(0.0104)*
PopD	*−0.0119****		*0.0378****		*0.0142*		*−0.0215**		*0.0234***
	(0.0325)		*(0.2105)*		*(0.0100)*		*(0.0125)*		*(0.0117)*
CTC	*0.0446****		*0.0197****		*0.0123**		*0.0440****		*0.0182****
	(0.0585)		*(0.0310)*		*(0.0650)*		*(0.0688)*		*(0.0661)*
DCPS	*0.0528****		*0.0310***		*−0.0155*		*0.0435****		*0.0382***
	(0.0369)		*(0.0114)*		*(0.0201)*		*(0.0135)*		*(0.0150)*
Constant	*−0.785****	*−0.446****	*−0.503****	*0.0451*	*0.0597*	*−0.660****	*−0.807****	*−0.470****	*−0.493****

Table 3 (continued)

Variables	Food security index								
	Driscoll-Kraay			Lewbel (2012) 2SLS internal and external					
	10	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
	(0.0471)	*(0.0322)*	*(0.0314)*	*(0.0116)*	*(0.0660)*	*(0.0385)*	*(0.0362)*	*(0.0231)*	*(0.0253)*
Observations	*618*	*595*	*540*	*636*	*553*	*592*	*543*	*509*	*467*
R-squared	*0.702*	*0.728*	*0.763*	*0.744*	*0.806*	*0.613*	*0.720*	*0.779*	*0.811*
Number of id	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*
F	*227.6*	*2256*	*86,054*	*19.25*	*214.4*	*187.7*	*158.9*	*297.2*	*201.7*

Standard errors in brackets, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Analysis of the dynamic character of our model

The method of generalized moments allows us to analyze the dynamic character of our model. Moreover, this technique also allows us to correct for endogeneity problems that might be present among our variables as shown in Fig. 3. Thus, this additional robustness allows us to maintain and even improve on previous results between the different measures of energy poverty and food security in sub-Saharan Africa. In general, our representations are well-specified based on the analytical tests. There is no rejection of the validity of the instruments by Hansen's test, and there is no rejection of the absence of second-order serial correlation by Hansen's test. Hansen's tests may be biased due to overidentification restrictions if there are a large number of instruments; Roodman (2009) recommends that the number of instruments be less than the number of countries. The results of the in-system GMM estimations generated a maximum of 25 instruments, which is less than the number of countries, so our results are valid and robust. There is a realization that countries should continue to devote a significant portion of their financing policies to the energy sector in order to reduce the number of people without access to electricity. This could enable large numbers of people to be lifted out of poverty and thus gain the ability to access food on a much higher income.

Table 5 presents the results using the generalized method of moments. The table shows that food security has a memory effect, hence the positive and significant effect of the delay of food security on itself. This also allows us to verify the dynamic nature in the long term between access to electricity and access to clean energy for cooking and food security in SSA. It appears that this method, by solving the endogeneity problems, confirms the results found above.

Transmission channels of energy poverty on food security in sub-Saharan Africa

The above findings are interesting because they show us that there is a direct link between access to energy and food security. Energy is certainly necessary for agri-food production along the value chain, especially for the production of crops, fisheries, livestock, and forests in agricultural areas. Indeed, energy is needed for post-harvest processing. The necessary food resources can be conserved by using renewable energy technologies such as solar dryers and refrigerators, in food storage and processing, food transport and distribution, and food preparation (Edward et al. 2020; FAO 2012). However, the estimates do not indicate the importance and significance of the channels from energy poverty to food security. The objective of this study is to determine how energy poverty affects food security. To do this, we use a causal mediation analysis. The impact of energy poverty on each transmission channel is presented in Table 6 and Fig. 4.

The results (Table 6) show that only the energy development index and the access to electricity have a positive and significant effect on the selected channels. All else being equal, increased energy access significantly boosts total employment, corruption, financial development, and urbanization (Koengkan et al. 2020; Mouraviev 2021; Nasirov et al. 2021). In contrast, the influence of energy poverty on income is not significant. In fact, a 1% increase in the energy development index leads to a significant increase in total employment, control of corruption, financial development, and urbanization by 0.2461, 3.9419, 4.5023, and 3.7814 units respectively. Similarly, a 1% increase in the rate of access to electricity significantly increases total employment, control of corruption, financial development, and urbanization by 0.0699, 0.0444, 0.0217, and 0.5075 respectively.

Since energy poverty partly explains the variation in transmission channels, we calculate the direct and indirect effects of certain measures of energy poverty on food security. As well as the total effect of energy development index and electricity access, Sobel (1982) product of coefficient method was used to calculate its indirect effects. Standard errors are corrected using the bootstrap procedure. The results are presented in Table 7.

Table 7 shows that energy poverty had a mediated effect on food security via these channels. Over the study

Table 4 Estimation with additional variables

Variables	Food security index								
	Fixed effects estimates						Driscoll-Kraay		
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
EDI	***0.172****	***0.1077****					***0.1607****	***0.1419****	
	(0.479)	*(0.642)*					*(0.185)*	*(0.715)*	
Elec			***0.0966****	***0.0375****					***0.0170****
			(0.0731)	*(0.0136)*					*(0.0138)*
Clean					***0.0225****	***0.0126****			
					(0.0129)	*(0.0163)*			
GDP	*−0.0982*	*0.0598*	*0.0165*	*0.0195*	*0.0242***	*0.0280****	*−0.0401*	*0.0218*	*−0.0877*
	(0.0123)	*(0.0125)*	*(0.0164)*	*(0.0156)*	*(0.0109)*	*(0.0100)*	*(0.0268)*	*(0.0198)*	*(0.0259)*
Fixe/T		*0.0592*		*0.0146***		*0.0200****		*0.0271****	
		(0.0489)		*(0.0601)*		*(0.0438)*		*(0.0651)*	
EmplT		*−0.0715*		*−0.0254***		*−0.0124*		*−0.0344****	
		(0.0978)		*(0.0120)*		*(0.0858)*		*(0.0899)*	
PopD		*−0.0103***		*0.0577*		*0.0371*		*0.0167**	
		(0.0471)		*(0.0601)*		*(0.0467)*		*(9.28e-05)*	
CTC		*−0.0467*		*5.42e-05*		*−0.0804*		*0.0166*	
		(0.0869)		*(0.0108)*		*(0.0752)*		*(0.0102)*	
DCPS		*0.0506****		*0.0629****		*0.0528****		*0.0142*	
		(0.0114)		*(0.0143)*		*(0.0983)*		*(0.0128)*	
Imp		*0.0669*		*0.0666*		*0.0702**		*−0.0107****	
		(0.0464)		*(0.0627)*		*(0.0390)*		*(0.0368)*	
Urb		*0.0685****		*0.0860***		*0.0124****		*0.0221***	
		(0.0222)		*(0.0340)*		*(0.0241)*		*(0.0895)*	
PST		*0.0140***		*−0.0117*		*0.0134****		*0.0174*	
		(0.0570)		*(0.0729)*		*(0.0497)*		*(0.0882)*	
Constant	*−0.0511*	*−0.379****	*−0.384****	*−0.706****	*−0.503****	*−1.072****	*0.0157*	*−0.0918*	*−0.663****
	(0.0572)	*(0.0999)*	*(0.0294)*	*(0.128)*	*(0.0273)*	*(0.0872)*	*(0.0112)*	*(0.0553)*	*(0.0352)*
Observations	*739*	*582*	*682*	*571*	*595*	*495*	*739*	*582*	*682*
R-squared	*0.461*	*0.514*	*0.213*	*0.255*	*0.355*	*0.522*	*0.768*	*0.808*	*0.591*
Number of id	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*
F	*299.3*	*56.90*	*87.40*	*18.07*	*153.5*	*49.38*	*5616*	*10,365*	*101.0*
Variables	Food security index								
	Driscoll-Kraay			Lewbel 2SLS (2012) internal and external					
	10	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
EDI				***0.1091****	***0.1632****				
				(2.182)	*(1.436)*				
Elec	***0.0111****					***0.0272****	***0.0123****		
	(0.0766)					*(0.0294)*	*(0.0184)*		
Clean		***0.0202****	***0.0150****					***0.0248****	***0.0151****
		(0.0311)	*(0.0923)*					*(0.0164)*	*(0.0186)*
GDP	*0.0227*	*−0.0196*	*0.0198*	*−0.0280*	*−0.0452*	*0.0215*	*0.0120*	*0.0844*	*0.0283*
	(0.0269)	*(0.0267)*	*(0.0192)*	*(0.0287)*	*(0.0245)*	*(0.0482)*	*(0.0371)*	*(0.0319)*	*(0.0284)*
Fixe/T	*0.0813****		*0.0366****	*0.0472***	*0.0225**	*0.0108****	*0.0955****	*−0.0138*	*0.0337***
	(0.0924)		*(0.0425)*	*(0.0184)*	*(0.0118)*	*(0.0181)*	*(0.0153)*	*(0.0152)*	*(0.0137)*
EmplT	*−0.0238**		*−0.0332****		*−0.092****		*−0.0163*		*−0.0132*
	(0.0123)		*(0.0106)*		*(0.0840)*		*(0.0116)*		*(0.0985)*
PopD	*−5.98e-05*		*0.0364****		*0.0149*		*3.09e-05*		*0.0473****

Table 4 (continued)

Variables	Food security index								
	Driscoll-Kraay			Lewbel 2SLS (2012) internal and external					
	10	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
	(5.74e-05)		*(9.83e-05)*		*(0.0109)*		*(0.0165)*		*(0.0117)*
CTC	*0.0341****		*0.0371****		*0.0115*		*0.0385****		*0.0271****
	(0.0893)		*(0.0730)*		*(0.0864)*		*(0.0106)*		*(0.0924)*
DCPS	*0.0702****		*0.0438***		*−0.0413*		*0.0604****		*0.0304**
	(0.0101)		*(0.0199)*		*(0.0153)*		*(0.0148)*		*(0.0157)*
Imp	*5.15e-05*		*−0.0147**		*−0.0101***		*0.0595*		*−0.0149**
	(0.0420)		*(0.0694)*		*(0.0469)*		*(0.0922)*		*(0.0815)*
Urb	*0.0365****		*0.0587****		*0.0321*		*0.0285*		*0.0555****
	(0.0118)		*(0.0554)*		*(0.0156)*		*(0.0227)*		*(0.0168)*
PST	*0.0125*		*−0.0135**		*0.0361*		*0.0130*		*−0.0146**
	(0.0789)		*(0.0729)*		*(0.0731)*		*(0.0109)*		*(0.0846)*
Constant	*−0.868****	*−0.446****	*−0.655****	*−0.0298**	*0.0409*	*−1.125****	*−0.937****	*−0.535****	*−0.617****
	(0.0542)	*(0.0322)*	*(0.0313)*	*(0.0161)*	*(0.107)*	*(0.125)*	*(0.0693)*	*(0.0394)*	*(0.0888)*
Observations	*571*	*595*	*495*	*643*	*546*	*444*	*413*	*397*	*366*
R-squared	*0.726*	*0.728*	*0.825*	*0.705*	*0.812*	*0.459*	*0.724*	*0.780*	*0.847*
Number of id	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*	*36*
F	*3048*	*2256*	*71,533*	*38.45*	*209.7*	*42.30*	*102.9*	*105.4*	*167.4*

Standard errors in brackets, ***$p<0.01$, **$p<0.05$, *$p<0.1$

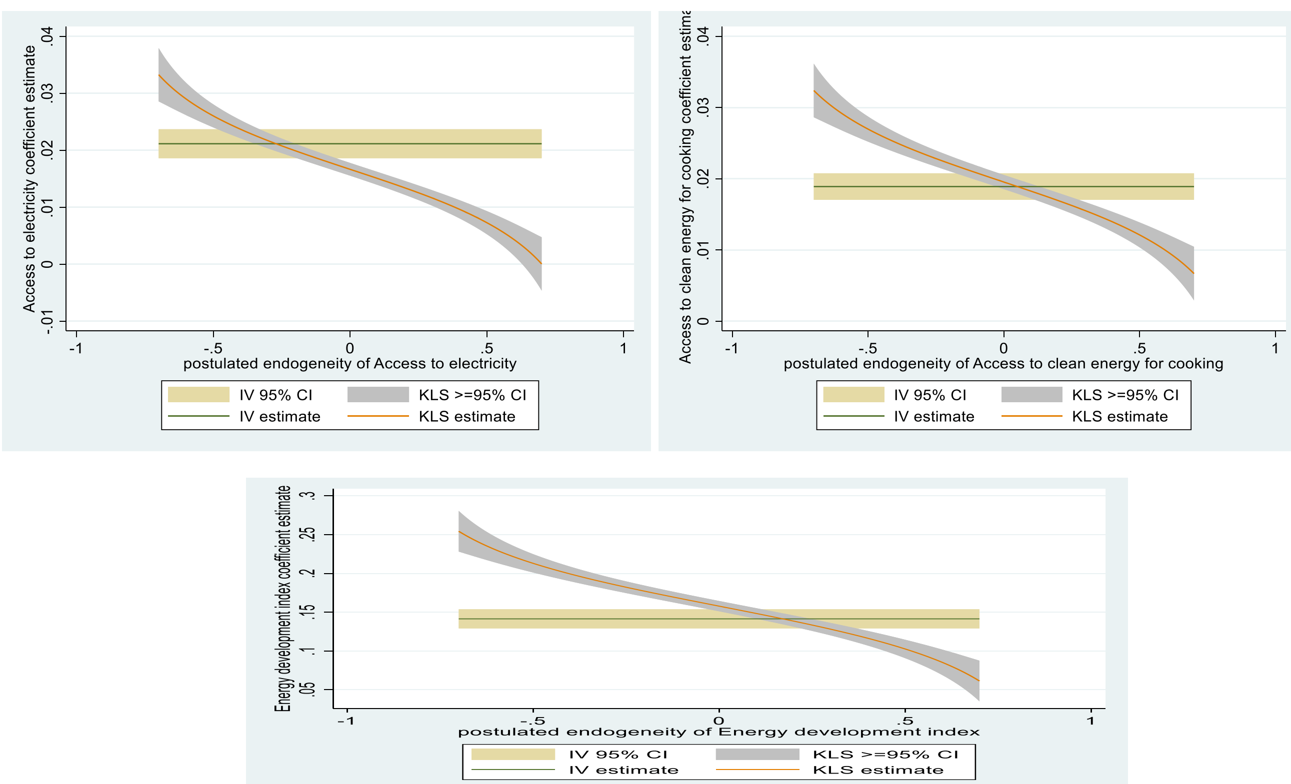

Fig. 3 Endogeneity test. Source: authors

Table 5 Estimation with generalized method of moments

Variables	Food security index											
	1	2	3	4	5	6	7	8	9	10	11	12
L.FSI	*0.835****	*0.851****	*0.820****	*0.810****	*0.920****	*0.919****	*0.914****	*0.899****	*0.974****	*0.971****	*0.966****	*0.971****
	(0.0130)	*(0.0130)*	*(0.0194)*	*(0.0208)*	*(0.0666)*	*(0.0635)*	*(0.0728)*	*(0.0899)*	*(0.0591)*	*(0.0583)*	*(0.0768)*	*(0.0855)*
EDI	*2.571****	*2.226****	*2.930****	*3.600****								
	(0.289)	*(0.310)*	*(0.449)*	*(0.549)*								
Elec					*0.0489****	*0.0510****	*0.0480****	*0.0573****				
					(0.0103)	*(0.0985)*	*(0.0903)*	*(0.0117)*				
Clean									*0.0734****	*0.0760****	*0.0810****	*0.0553***
									(0.0187)	*(0.0195)*	*(0.0231)*	*(0.0237)*
GDP/h		*0.0157****	*0.0139****	*0.0192****		*0.0171****	*0.0164****	*0.0153****		*0.0148****	*0.0142****	*0.0171****
		(0.0302)	*(0.0388)*	*(0.0423)*		*(0.0375)*	*(0.0387)*	*(0.0430)*		*(0.0191)*	*(0.0203)*	*(0.0243)*
Fixed-T		*0.0140*	*0.0288**	*1.0106*		*0.0512****	*0.0604****	*0.0467****		*0.0247***	*0.0288***	*0.0234***
		(0.0123)	*(0.0163)*	*(0.0002)*		*(0.0171)*	*(0.0141)*	*(0.0131)*		*(0.0104)*	*(0.0109)*	*(0.0108)*
EmplT			*−0.0816***	*−0.0514*			*0.0160*	*−0.0216*			*0.0336***	*0.0204*
			(0.0310)	*(0.0475)*			*(0.0231)*	*(0.0223)*			*(0.0165)*	*(0.0199)*
PopD			*0.0521*	*0.0325*			*0.3105****	*−0.0316*			*0.0305****	*5.19e-06*
			(0.0321)	*(0.0215)*			*(0.0205)*	*(0.3605)*			*(0.0205)*	*(0.0235)*
CTC				*0.0105*				*0.0376*				*0.0140*
				(0.0303)				*(0.0239)*				*(0.0114)*
DCPS				*−0.0973****				*0.0407**				*0.0122*
				(0.0319)				*(0.0223)*				*(0.0137)*
Imp				*−0.0426**				*−0.0415*				*−0.0154*
				(0.0229)				*(0.000195)*				*(0.0116)*
Urb				*−0.0101****				*−0.0225*				*−0.0046*
				(0.0267)				*(0.0261)*				*(0.0169)*
PST				*0.0746*				*0.0783**				*0.0591**
				(0.0516)				*(0.0437)*				*(0.0343)*
Constant	*0.0991***	*0.0854***	*0.0209**	*0.0704****	*−0.184****	*−0.200****	*−0.197****	*−0.259****	*−0.0152*	*−0.0673*	*−0.0193***	*−0.0267***
	(0.0419)	*(0.0382)*	*(0.0111)*	*(0.0208)*	*(0.0417)*	*(0.0401)*	*(0.0384)*	*(0.0508)*	*(0.0392)*	*(0.0473)*	*(0.0822)*	*(0.0113)*
Observations	*720*	*676*	*649*	*553*	*669*	*638*	*638*	*547*	*576*	*555*	*555*	*466*
Number of id	*36*	*36*	*36*	*33*	*36*	*36*	*36*	*33*	*36*	*36*	*36*	*33*
Instruments	*16*	*18*	*20*	*25*	*16*	*18*	*20*	*25*	*16*	*18*	*20*	*25*
AR (1)	*4.79e-05*	*0.0163*	*0.0118*	*0.0219*	*9.16e-05*	*0.0337*	*0.0349*	*0.0595*	*0.0445*	*0.0734*	*0.0769*	*0.0780*
AR (2)	*0.331*	*0.849*	*0.457*	*0.654*	*0.940*	*0.133*	*0.132*	*0.161*	*0.321*	*0. 466*	*0.595*	*0. 529*
Hansen (OIR)	*0.0779*	*0.440*	*0.648*	*0.437*	*0.183*	*0.144*	*0.136*	*0.200*	*0.427*	*0.639*	*0.626*	*0.651*

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

Table 6 Results of the structural model

Variables	EDI	Elec	Constant	Observations
GDP/h	*0.0936 (0.0498)*		*2.2233*** (0.3633)*	*630*
EmplT	*0.2461*** (0.0471)*		*2.0592*** (0.0578)*	*644*
CTC	*3.9419*** (0.5988)*		*4.5511*** (0.2904)*	*644*
DCPS	*4.5023*** (0.4337)*		*1.5973*** (0.6351)*	*644*
Urb	*3.7814*** (0.7327)*		*2.0062*** (0.9878)*	*644*
GDP		*– 0.0336 (0.0832)*	*2.6155 (3.6564)***	*618*
EmplT		*0.0699*** (0.0331)*	*1.0664*** (1.0864)*	*618*
CTC		*0.0444*** (0.1656)*	*2.0095*** (1.4974)*	*618*
DCPS		*0.0217*** (0.1031)*	*1.1233*** (1.0308)*	*618*
Urb		*0.5075*** (0.0152)*	*2.7002*** (0.9715)*	*618*

Bootstrap standard errors in parentheses; *** indicates statistical significance at 1% level

period, energy poverty reduction indirectly improved food security through total employment, corruption, financial development, and urbanization. In addition to calculating the total impact of energy poverty on food security, we attempt to calculate the contribution of each channel to it. We find that about 6% and 9% of the total positive indirect effects of the energy development index on food security are due to total employment and urbanization respectively. Similarly, we find that 10%, 16%, and 14% of the positive indirect effect of access to electricity on food security come from corruption, financial development, and urbanization.

The indirect positive effect of improved access to energy on food security can be explained by the fact that access to energy contributes to improving the financial system by creating favorable conditions for industrialization and improving the profitability of enterprises in general. This improvement in the profitability of enterprises will be beneficial for employment

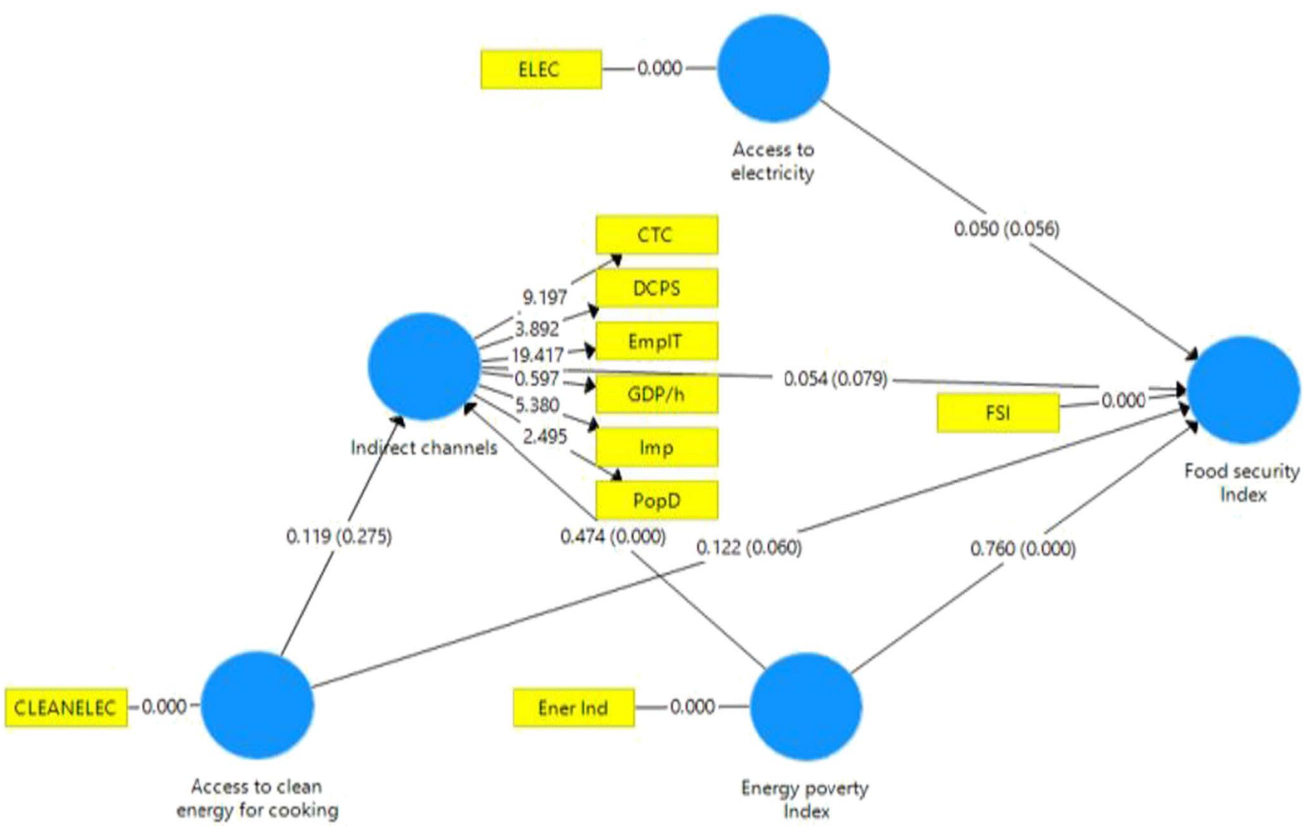

Fig. 4 Transmission channels. Source: authors

Table 7 Indirect effects of energy poverty on food security

Variables	EmplT	Urb	CTC	DCPS	Urb
EDI	*−0.8026*** (0.0797)*	*1.0807*** (0.211)*			
ELEC			*0.0048*** (0.0091)*	*0.0092*** (0.0027)*	*0.0095*** (0.0095)*
Controls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Constant	*2.0434*** (0.0078)*	*2.649*** (0.0649)*	*2.0095*** (1.4974)*	*1.1233*** (1.0308)*	*2.7002*** (0.9715)*
% of mediated effect	*6%*	*9%*	*10%*	*16%*	*14%*

Standard errors in brackets, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

and therefore savings. Moreover, financial institutions are increasingly keen on digital tools because of the strong potential for closer contact with the customer and the facilitation of control. However, these technologies are highly dependent on energy. In addition, access to energy offers opportunities in terms of food preservation and business opportunities for urban residents. Therefore, income-generating activities driven by energy access can also lead to boosting the production and efficiency of existing businesses and thus generate new jobs and income (Riva et al. 2018). According to Gibson and Olivia (2010), a survey of 4,000 rural Indonesian households shows that improving the quality of electricity infrastructure has a positive impact on the growth of rural non-farm enterprises. They also find that it contributes to job creation and income growth, livelihood diversification and poverty reduction in developing countries.

Finally, access to electricity increases income, which in turn increases people's purchasing power, with a positive impact on people's food security. Thus, the resolution of food insecurity in SSA must be driven in large part by increasing energy supply. Our results cannot be directly compared to existing research, since transmission channels have not been emphasized in previous studies.

Conclusion and policy implications

Access to energy, as defined in SDG 7, is an important component of decent livelihoods and is therefore strictly linked to the achievement of the overall goal of sustainable development, and thus well-being (SDG 3). Although it has a significant impact on many dimensions of the SDGs, this study focused on its effect on the level of food security (SDG 2) in sub-Saharan Africa. Although the literature on this issue has largely focused on the micro-level, this study is one of the first to empirically examine the effect of energy poverty on food security in SSA. The results revealed that a reduction in energy poverty as measured by the energy development index, access to electricity, and access to clean energy for cooking has a positive and significant effect on food security in SSA. These results support many of the policies that African countries have put in place in recent years to close the gap in access to electricity and clean cooking energy. There is therefore a need for governments to devote more financial resources to the energy sector in order to influence food security outcomes in sub-Saharan Africa. The results also showed that various energy indicators, such as the energy development index, access to electricity and access to clean cooking energy, have a direct and indirect impact on food security. This is through channels such as employment, control of corruption, financial development and urbanisation. This finding can inform policymakers on prioritizing investments in proximity access to electricity for vulnerable households, especially in rural areas, including through off-grid decentralized electricity systems (such as mini-grids, micro-grids, and "stand-alone" systems for domestic and productive use) which are increasingly seen as offering more cost-effective, faster, and flexible solutions for rural and even urban electrification. This could lead to a further improvement in food security.

Appendix

Table 8 Definitions and sources of the key variables

Variables	Abbreviation	Definitions	Sources
Access to clean energy for cooking	Clean	Access to clean fuels and technologies for cooking is the proportion of total population (% of population)	WDI
Access to electricity	Elec	Access to electricity is the percentage of population with access to electricity (% of population)	WDI
Energy development index	EDI	ACP (access to clean energy, access to electricity and renewable energy consumption)	WDI
Food security index	FSI	ACP (availability, accessibility, stability, and usability)	FAOSTAT
GDP per capita growth	GDP/h	Annual percentage growth rate of GDP per capita based on constant local currency (annual %)	WDI
Fixed telephone	Fixed-T	Fixed telephone subscriptions refers to the sum of active number of analogue fixed telephone lines (per 100 people)	WDI
Employers, total	EmplT	Employers are those workers who are working on their own account or with one or a few partners (% of total employment)	WDI
Population density	PopD	Population density is midyear population divided by land area in square kilometers (people per sq. km of land area)	WDI
Financial development	DCPS	Domestic credit to private sector by banks refers to financial resources provided to the private sector by other depository corporations (% of GDP)	WDI
Imports of goods and services	Imp	Imports of goods and services comprise all transactions between residents of a country and the rest of the world involving (BoP, current US$)	WDI
Urban population (% of total population)	Urb	Urban population refers to people living in urban areas (%population)	WDI
Political stability and absence of violence/terrorism	PST	Political stability and absence of violence/terrorism measures perceptions of the likelihood of political instability	WGI
Control of corruption: estimate	CTC	Control of corruption captures perceptions of the extent to which public power is exercised for private gain	WGI

Variables that use to construct FSI: prevalence of undernourishment (percent) (3-year average); number of people undernourished (million) (3-year average); average dietary energy supply adequacy (percent) (3-year average); average value of food production (constant 2004–2006 I$/cap) (3-year average); share of dietary energy supply derived from cereals, roots, and tubers (kcal/cap/day) (3-year average); average protein supply (g/cap/day) (3-year average); average supply of protein of animal origin (g/cap/day) (3-year average); percentage of population using at least basic drinking water services (percent); percentage of population using at least basic sanitation services (percent); prevalence of obesity in the adult population (18 years and older); prevalence of anemia among women of reproductive age (15–49 years); percent of arable land equipped for irrigation (percent) (3-year average); value of food imports in total merchandize exports (percent) (3-year average); per capita food production variability (constant 2004–2006 thousand int$ per capita); per capita food supply variability (kcal/cap/day).

Countries: Angola, Benin, Botswana, Burkina Faso, Cabo Verde, Cameroon, Central African Republic, Chad, Congo, Dem, Rep, Congo, Rep, Cote d'Ivoire, Djibouti, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo.

Author contribution Thierry Messie Pondie: conceptualization, introduction, methodology, interpreted results, writing—original draft preparation. Fon Dorothy Engwali: project administration, formal analysis, supervision, validation, finalizing the manuscript, revised draft, writing—original draft preparation, review, and editing. Bruno Emmanuel Ongo Nkoa: visualization, writing—original draft preparation. Edmond Noubissi Domguia: literature review, review, and editing.

Data availability Data are available on request.

Declarations

Ethical approval and consent to participate Not applicable. Our study did not use any kind of individual data such as video.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abulibdeh A, Zaidan E (2020) Managing the water-energy-food nexus on an integrated geographical scale. Environ Dev 33:100498

Acharya RH, Sadath AC (2019) Energy poverty and economic development: household-level evidence from India. Energy Build 183:785–791

Action P (2013) Poor people's energy outlook 2012: energy for earning a living: Practical Action Publishing

Ahlborg H, Sjöstedt M (2015) Small-scale hydropower in Africa: socio-technical designs for renewable energy in Tanzanian villages. Energy Res Soc Sci 5:20–33

Al-Maadid A, Caporale GM, Spagnolo F, Spagnolo N (2017) Spillovers between food and energy prices and structural breaks. Int Econ 150:1–18

Anser MK, Osabohien R, Olonade O, Karakara AA, Olalekan IB, Ashraf J, Igbinoba A (2021) Impact of ICT adoption and governance interaction on food security in West Africa. Sustainability 13(10):5570

Arellano M, Bond S (1991) Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev Econ Stud 58(2):277–297

Arellano M, Bover O (1995) Another look at the instrumental variable estimation of error-components models. J Econom 68(1):29–51

Badami MG, Ramankutty N (2015) Urban agriculture and food security: a critique based on an assessment of urban land constraints. Glob Food Sec 4:8–15

Banerjee R, Mishra V, Maruta AA (2021) Energy poverty, health and education outcomes: evidence from the developing world. Energy Econ 101:105447

Baum CF, Lewbel A, Schaffer ME, Talavera O (2012) Instrumental variables estimation using heteroskedasticity-based instruments. Paper presented at the United Kingdom Stata User's Group Meetings

Bazzi S, Clemens MA (2013) Blunt instruments: avoiding common pitfalls in identifying the causes of economic growth. Am Econ J Macroecon 5(2):152–186

Blundell R, Bond S (1998) Initial conditions and moment restrictions in dynamic panel data models. J Econom 87(1):115–143

Boardman B (1991) Fuel poverty: from cold homes to affordable warmth: Pinter Pub Limited

Burchi F, De Muro P (2012) A human development and capability approach to food security: conceptual framework and informational basis. Background paper, 8

Campi M, Dueñas M, Fagiolo G (2021) Specialization in food production affects global food security and food systems sustainability. World Dev 141:105411

Candelise C, Saccone D, Vallino E (2021) An empirical assessment of the effects of electricity access on food security. World Dev 141:105390

Chambers R (1987) Sustainable livelihoods, environment and development: putting poor rural people first

Chisasa J, Makina D (2012) Trends in credit to smallholder farmers in South Africa. Int Bus Econ Res J (IBER) 11(7):771–784

Churchill SA, Smyth R (2021) Locus of control and energy poverty. Energy Econ 104:105648

Conway GR (1985) Agroecosystem analysis. Agric Admin 20(1):31–55

De Schutter O (2010) Rapport du rapporteur spécial sur le droit à l'alimentation. Nations Unies, Conseil des Droits de l'homme: A/HRC/16/49

Domguia EN, Pondie TM, Ngounou BA, Nkengfack H (2022) Does environmental tax kill employment? Evidence from OECD and non-OECD countries. J Clean Prod 134873

Driscoll JC, Kraay AC (1998) Consistent covariance matrix estimation with spatially dependent panel data. Rev Econ Stat 80(4):549–560

Edward B, Dawit M, Kester W (2020) Capturing the productive use dividend valuing the synergies between rural electrification and smallholder agriculture in Ethiopia. Rocky Mountain Institute Insight Brief, April 2020

FAO (2012) The State of food and agriculture: investing in agriculture for a better future. Food and Agriculture Organization, Rome

FAO, FIDA, OMS, PAM, & UNICEF (2018) The state of food security and nutrition in the world. Building Resilience to Climate Change for Food Security and Nutrition. Rome, FAO

FAO, IFAD, UNICEF, WFP, & WHO (2022) The state of food security and nutrition in the world 2022. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO

FAOSTAT (2022) https://www.fao.org/faostat/fr/#home

Gibson J, Olivia S (2010) The effect of infrastructure access and quality on non-farm enterprises in rural Indonesia. World Dev 38(5):717–726

Healy JD, Clinch JP (2004) Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. Energy Policy 32(2):207–220

Herrero ST (2017) Energy poverty indicators: a critical review of methods. Indoor Built Environ 26(7):1018–1031

Hills J (2012) Getting the measure of fuel poverty: final report of the fuel poverty review

Howells M, Hermann S, Welsch M, Bazilian M, Segerström R, Alfstad T, . . ., Van Velthuizen H (2013) Integrated analysis of climate change, land-use, energy and water strategies. Nat Clim Change 3(7):621–626

IEA (2010) Energy poverty: how to make modern energy access universal? In: Int Energy Agency, United Nations Dev., Program. United Nations Ind Dev Organ

IEA, IRENA, ONU, BM, & OMS (2020) Tracking SDG 7: the energy progress report. World Bank. Washington DC

IEA (2014) World energy outlook 2014. Int Energy Agency Program. United Nations Ind Dev Organ

Islam MR, Sarker PC, Ghosh SK (2017) Prospect and advancement of solar irrigation in Bangladesh: a review. Renew Sustain Energy Rev 77:406–422

Kadjo D, Ricker-Gilbert J, Alexander C et al (2016) Estimating price discounts for lowquality maize in sub-Saharan Africa: evidence from Benin. World Dev 77:115–128

Keskinen M, Someth P, Salmivaara A, Kummu M (2015) Water-energy-food nexus in a transboundary river basin: the case of Tonle Sap Lake. Mekong River Basin Water 7(10):5416–5436
Kirubi C, Jacobson A, Kammen DM, Mills A (2009) Community-based electric micro-grids can contribute to rural development: evidence from Kenya. World Dev 37(7):1208–1221
Koengkan M, Fuinhas JA, Santiago R (2020) The relationship between CO2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market. J Environ Econ Policy 9(4):383–401
Lewbel A (2012) Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. J Bus Econ Stat 30(1):67–80
McCordic C, Riley L, Raimundo I (2021) Household food security in Maputo: the role of Gendered Access to education and employment. Dev South Afr 38(5):816–827
Mouraviev N (2021) Renewable energy in Kazakhstan: challenges to policy and governance. Energy Policy 149:112051
Mushtaq S, Maraseni TN, Maroulis J, Hafeez M (2009) Energy and water tradeoffs in enhancing food security: a selective international assessment. Energy Policy 37(9):3635–3644
Nasirov S, Girard A, Peña C, Salazar F, Simon F (2021) Expansion of renewable energy in Chile: analysis of the effects on employment. Energy 226:120410
Nkiaka E, Okpara UT, Okumah M (2021) Food-energy-water security in sub-Saharan Africa: quantitative and spatial assessments using an indicator-based approach. Environ Dev 40:100655
Ponguane S (2021) Prevention of food losses across the value chain in Africa
Ribeiro JMP, Berchin II, da Silva Neiva S, Soares T, de Albuquerque Junior CL, Deggau AB, . . ., de Andrade Guerra JBSO (2021) Food stability model: a framework to support decision-making in a context of climate change. Sustain Dev 29(1):13–24
Riva F, Ahlborg H, Hartvigsson E, Pachauri S, Colombo E (2018) Electricity access and rural development: review of complex socio-economic dynamics and causal diagrams for more appropriate energy modelling. Energy Sustain Dev 43:203–223
Roodman D (2009) How to do xtabond2: an introduction to difference and system GMM in Stata. Stand Genomic Sci 9(1):86–136
Saing CH (2018) Rural electrification in Cambodia: does it improve the welfare of households? Oxf Dev Stud 46(2):147–163
Sambodo MT, Novandra R (2019) The state of energy poverty in Indonesia and its impact on welfare. Energy Policy 132:113–121
Sen A (1981) Ingredients of famine analysis: availability and entitlements. Q J Econ 96(3):433–464
Sen A (1985) Commodities and capabilities. Amsterdam New York New York, NY: USA: North-Holland Sole distributors for the USA and Canada, Elsevier
Sen A (1993) Capability and well-being73. Qual Life 30:1–445
Slimane MB, Huchet-Bourdon M, Zitouna H (2016) The role of sectoral FDI in promoting agricultural production and improving food security. Int Econ 145:50–65
Smith LC, Haddad L (2002) How potent is economic growth in reducing undernutrition? What are the pathways of impact? New cross-country evidence. Econ Dev Cult Change 51(1):55–76
Sobel ME (1982) Asymptotic confidence intervals for indirect effects in structural equation models. Sociol Methodol 13:290–312
Sola P, Ochieng C, Yila J, Iiyama M (2016) Links between energy access and food security in sub Saharan Africa: an exploratory review. Food Security 8(3):635–642
Soriano B, Garrido A (2016) How important is economic growth for reducing undernourishment in developing countries? Food Policy 63:87–101
Starr C (1972) Energy, power and society. Scientific American (September)
Stock JH, Wright JH, Yogo M (2002) A survey of weak instruments and weak identification in generalized method of moments. J Bus Econ Stat 20(4):518–529
Sustainable-Development-Goals, R. o. t. (2021) https://unstats.un.org›sdgs›report ›
Taghizadeh-Hesary F, Rasoulinezhad E, Yoshino N (2019) Energy and food security: linkages through price volatility. Energy Policy 128:796–806
Thomson H, Snell CJ, Liddell C (2016) Fuel poverty in the European Union: a concept in need of definition? People, Place & Policy Online, 5–24
Timmer CP (2000) The macro dimensions of food security: economic growth, equitable distribution, and food price stability. Food Policy 25(3):283–295
Tiwari S, Zaman H (2010) The impact of economic shocks on global undernourishment. World Bank Policy Research Working Paper (5215)
Tod A, Thomson H (2016) Health impacts of cold housing and energy poverty Energy poverty handbook (pp. 39–56): Publications Office of the European Union
Vijay V, Armsworth PR (2021) Pervasive cropland in protected areas highlight trade-offs between conservation and food security. Proc Natl Acad Sci 118(4):e2010121118
World-Bank (2017) State of electricity access report. International Bank for Reconstruction and Development, Washington DC
World-Bank (2022) World development indicators. http://datatopics.worldbank
Zakari A, Toplak J, Tomažič LM (2022) Exploring the relationship between energy and food security in Africa with instrumental variables analysis. Energies 15(15):5473

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.