Energy Economics 109 (2022) 105953

Contents lists available at ScienceDirect

Energy Economics

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

Operationalizing affordability criterion in energy justice: Evidence from rural West Africa

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ARTICLE INFO

JEL classification codes:
O12
Q40
O13

Keywords:
Energy poverty
Energy justice
Opportunity costs
Traditional biomass

ABSTRACT

Affordability of energy is at the heart of the concept of energy poverty but also an important criterion for energy justice globally. Yet, in developing countries where households predominantly rely on traditional energy sources, measuring the cost of energy goes beyond the price of the fuel and includes other non-monetary costs, such as the time spent and the distance travelled for fuel collection. This paper thereby proposes a redefinition as well as an operationalization of the affordability criterion within the energy justice framework. The outcomes are applied to data obtained in rural Benin, Senegal and Togo. The results suggest that, on average, the opportunity costs related to energy collection represent between 29 and 35% of household income in rural areas. Additionally, failing to account for the non-monetary costs of energy consumption in rural locations may lead to categorizing at least 17% of households as having access to affordable energy, when in fact these households spend substantial amount of time in fuel collection. The study also suggests that reducing income poverty and promoting better access to modern energy sources, through rural electrification programs, are critical to ensure energy affordability in rural West Africa.

1. Introduction

Achieving energy affordability[1] for better energy justice remains a key priority for households and policy makers in the developing world (Sovacool et al., 2017; Jodoin, 2021). In this vein, Sovacool et al. (2016) highlighted the need for governments to ensure that the provision of energy services does not become a 'financial burden for consumers, especially the poor'. To attain this outcome, a central task is to devise a metric that adequately apprehends households' energy affordability in developing countries.

In recent years, academic works have defined affordability in relation to the financial burden of energy consumption and operationalized energy affordability using the share of energy expenditure in household income. While this approach may be appropriate in developed and urban communities, in the context of developing and rural societies – where households mostly rely heavily on traditional energy sources – it has a number of shortcomings.

One of the most prominent is that it evaluates expenses or direct costs but ignores non-monetary costs (opportunity costs), thereby leading to an overestimation of energy affordability. For instance, in rural African communities, most households rely on traditional biomass for cooking, which is mostly collected freely from the environment. Yet, household members often need to travel a long distance and spend considerable amount of time in fuel collection – at the expense of productive or income generating activities, community works, and leisure, etc. Due to the failure to account for these contextual specificities and non-monetary costs of fuel, energy in such cases is likely to be considered as affordable (due to low expenditure-to-income ratio) when in fact it is not.

The objective of this paper is to offer a different approach to measuring energy affordability. Specifically, the study accounts for the opportunity costs of energy use in operationalizing energy affordability in rural West Africa. The paper uses primary data collected from rural households' survey. First, we estimate the opportunity cost of energy consumption using information on the time spent on fuel collection and the transportation cost. Second, energy affordability is operationalized

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[1] According to Sovacool et al. (2017), the energy justice framework (EJF) includes ten (10) principles or criteria namely; availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity, responsibility, resistance and intersectionality. These criteria are considered as the essential pillars of global, regional or national energy justice.

https://doi.org/10.1016/j.eneco.2022.105953
Received 30 January 2021; Received in revised form 10 February 2022; Accepted 6 March 2022
Available online 9 March 2022
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and measured by taking into account the opportunity costs related to fuel use, thereby addressing one of the main drawbacks of the mainstream measure of affordability, namely, the share of income spent on energy. Additionally, the estimates of opportunity costs and energy affordability are compared between three representative countries, namely, Benin, Togo, and Senegal[2]. Third, the study investigates and compares the correlates of energy affordability across countries, with an emphasis on the role of household characteristics, natural resource endowment and rural electrification programs.

The contribution of this paper is two-fold. First, although it is widely acknowledged that in energy poor developing countries, several households' members (especially women and children) face great hardship in biomass collection, little attention has been given to quantifying the opportunity costs of the drudgery that fuel collection or purchase entails (World Bank, 2004; González-Eguino, 2015; Kanagawa and Nakata, 2007). Second, by examining the role of socio-economic and environmental factors affecting energy affordability, the paper provides relevant information for policy-making aiming at promoting affordability of energy access in rural dwellings in the regional context and beyond.

The remainder of the paper is organized as follows. Section 2 discusses the main challenges of operationalizing affordability and the measurement approaches proposed in the existing literature. Section 3 describes the measurement of opportunity costs of energy consumption. Section 4 provides a discussion of the data used. Section 5 presents the estimation results, and Section 6 concludes the paper with some policy implications.

2. Operationalizing and measuring the affordability criterion

2.1. Operationalizing affordability: Some key issues

Within the energy justice framework, the affordability criterion could be considered as one of the less 'complex and controversial' principles. Meanwhile, its conceptualization and measurement raise a number of challenges. First, in extant definitions of affordability, the types of energy services that should be considered has remained largely unspecified (Sovacool et al., 2016; Sovacool and Dworkin, 2015). Consequently, the choice of energy services to include has become arbitrary and varies across the literature. Some authors argued for a panoply of energy services to be considered when defining affordability, while others focus on the energy services that fulfill basic human needs (Sovacool, 2011; Sadath and Acharya, 2017[3]). Of course, in cross-country studies, the type of energy service considered in measuring affordability must be essential for human well-being, and the service or the equipment needed by the households should be available in the local context. Hence, a satisfiable affordability criterion in many rural areas in West Africa would include cooking, lighting and space heating (depending on the geographical locations and climatic conditions), which are generally considered as essential for human well-being.

Second, the affordability criterion is commonly defined in relation to energy services, such as warm homes or well-lit dwelling spaces, and fails to account for the quantity of energy consumed. Hence, it assumes that for a given energy service (e.g., lighting) all individuals have equal energy consumption – in other words, there is no energy consumption shortfall for the poor (Herrero, 2017). To address this challenge, a number of scholars conceptualized affordability in terms of the quantity of energy consumed rather than mere energy services (Sovacool and Mukherjee, 2011). Lastly, affordability as defined in the literature puts emphasis on energy services, and not on the type or source of energy per se[4] (Sovacool et al., 2016, 2017; Sovacool and Dworkin, 2015). Hence, affordability is not a sufficient condition for energy access under the capability approach[5] (Pachauri and Spreng, 2011), and the principle ought to be combined with other criteria, such as, the availability principle: providing 'sufficient energy resources of high quality' (Sovacool et al., 2017, pg. 687). Consequently, affordability is one constitutive element of what is a means toward an end, which is improved capabilities.

2.2. Measurements of energy poverty and affordability

In empirical literature, energy poverty is measured in various ways using objective and subjective indicators. The former relies on explicitly and independently defined criteria, while the latter is based on the household members' perceptions about their energy poverty status or their ability to meet basic energy needs (Ntaintasis et al., 2019). The objective indicators of energy poverty include unidimensional and

Table 1
Measures of energy poverty.

Energy poverty Measurements	Definition	Related Literature
Objective measures		
Unidimensional indicators		
• Expenditure-based approach	Evaluates energy poverty level in relation to affordability. It is based on the share of energy expenditure in income.	Boardman (1991); Price et al. (2012); ESMAP (2015); Churchill et al. (2020)
• Physical threshold approach	Evaluates energy poverty by comparing household energy consumption to a given standard, defined as the minimum physical energy consumption required to meet basic energy needs.	González-Eguino (2015); Chakravarty and Tavoni (2013); Barnes et al. (2011)
• 'Income poverty line' approach	Evaluates energy poverty based on the income poverty line.	Foster et al. (2000); Hills (2011); Legendre and Ricci (2015)
• 'Technological threshold' approach	Evaluates energy poverty based on the sources of energy (i.e., modern versus traditional sources)	González-Eguino (2015); IEA (2017)
Multidimensional indicators		Pachauri et al. (2004); Nussbaumer et al. (2012); Sadath and Acharya (2017); Tait (2017); Churchill and Smyth (2021)
Subjective measures		Aristondo and Onaindia (2018); Ntaintasis et al. (2019); Churchill et al. (2020); Churchill and Smyth (2021)

Note: The list of related literature is non-exhaustive.

[2] Benin and Senegal are lower middle-income countries while Togo is categorized as low-income country according to the World Bank (2021). Furthermore, Senegal is dominated by the Sahelian (arid) and the Sudanic (semi-arid) climate zones. Meanwhile, Benin and Togo have a combination of Sudanic and Guinean (sub-humid) zones with relatively higher presence of woody plants. These differences in climatic conditions are likely to influence the availability and access to biomass by households (FAO, 1985).

[3] For instance, Sovacool (2011) cites space heating, water heating, cooking family meals, lighting, and household appliances while Sadath and Acharya (2017) considered only lighting and cooking.

[4] For example, a household may have access to affordable cooking or lighting energy irrespective of the type of energy source that it uses (biomass fuel versus LPG, or kerosene versus electricity).

[5] As per the example, the use of traditional energy sources would not ensure that the capabilities of the household are preserved.

multidimensional measures (see Table 1 for a summary of energy poverty measures as well as related literature). Under the unidimensional methods, four broad approaches are used, namely, the expenditure-based, the 'physical threshold', 'income poverty line', and the 'technological threshold' approaches (Herrero, 2017; González-Eguino, 2015).

The expenditure-based approach defines energy poverty as the lack of energy affordability[6] (Price et al., 2012; Churchill et al., 2020). Specifically, a household is energy poor – and thus, has no access to affordable energy – if its expenditure on energy services exceeds a given threshold, above which the provision of energy services would become a financial burden for consumers (Boardman, 1991; Legendre and Ricci, 2015). The threshold is usually set to 10%[7] (Sovacool and Dworkin, 2015; Boardman, 1991). The Energy Sector Management Assistance Program (ESMAP, 2015)'s multi-tier approach recently considered a 5% threshold for cooking energy and a 5% for lighting energy.

Traditional expenditure-income measures use the share of household income spent on energy (actual expenditure rather than required). This approach gives a picture of the financial burden that energy consumption places on the household budget. However, it does not account for the quantity of energy consumption and assumes that, at all times, individuals have an end-use energy consumption that fulfils their basic needs (Herrero, 2017). Thus, some studies used the share of income that the household would need to meet an 'a priori-evaluated' energy services requirement, rather than actual expenditure (Boardman, 1991; Hills, 2012).

Despite their relative simplicity, the expenditure-based indicators of energy poverty have a number of limitations. First, rich households with high energy consumption may be wrongly categorize as energy poor. Second, the measures tend to be sensitive to variations in fuel prices as well as the efficiency of household appliances, leading to interpretation challenges (Pachauri et al., 2004; Hills, 2012). Third, these measures fail to account for drudgery and other inconveniences related to the fuel used (non-monetary costs of fuel) and may result in an underestimation of energy poverty (i.e., an overestimation of affordability) in locations where traditional biomass is collected for free from the environment[8].

3. Measuring the opportunity costs of energy consumption

Opportunity costs are defined as the forgone opportunities or benefits resulting from a person's choice between different alternatives (Buchanan, 1991). It is based on the idea of the scarcity of resources, such as time or money. Time poverty – which can be defined as the lack of time and flexibility for economic opportunities, leisure and other activities that a person values because of labor and other (imposed) tasks – determines people capacity to allocate labor time for productive activities and to respond to economic incentives. The collection of traditional biomass fuel and the use of traditional lighting fuel, such as kerosene, entails much drudgery, limiting people's engagement in paid work, human capital development or leisure. Moreover, the use of this kind of fuel comes with non-internalized externalities, such as effects on human health from indoor smoke exposure, forest degradation, and the impacts of GHG emissions.

In many rural societies, women are traditionally responsible for food preparation and fuel management tasks within the household, and often need to travel for a long distance and spend considerable amount of time to collect firewood or purchase kerosene for lightening (World Bank, 2004). Although, traditional biomass fuels are often collected for free in many parts of rural Africa, the time spent by household members to access it usually leads to high opportunity costs. Additionally, the use of modern energy reduces the time spent on cooking and other activities that are mainly performed by women. For instance, Practical Action (2012) shows that when modern energy services are available for agro-processing tasks such as milling, grinding or de-husking, women in Mali save between 2 and 6 h a day, which could be allocated to income generating activities[9].

To evaluate the opportunity costs of energy consumption, the inconvenience related to fuel use is monetized using the forgone market wage of adult household members as a result of the time spent on fuel collection and the transportation costs. As presented in equation (1), the total number of hours, t_i, spent on fuel collection by household members are converted in monetary terms using the minimum wage rate[10] (see equation 1). The forgone labor income is then adjusted using the prevailing rural unemployment rate, μ, in each country[11]. Furthermore, a weight, w_i, representing the extent of children's participation in fuel collection[12] is assigned to each household. Specifically, w takes the value '1' if children in the household do not participate or have little involvement in fuel collection, '0.5' if children participate equally, and '0' if they are mainly responsible for fuel collection. The opportunity cost of labor is added to the income lost due to the cost of transportation. The obtained value, thus, represents an approximation of the household opportunity costs of energy consumption[13].

$$Opportunity\ Cost_i = Wage\ rate_i * t_i * (1-\mu) * w_i + Transportation\ Cost_i \quad (1)$$

Given the present definition, 'zero' opportunity cost is not necessarily assigned to households using modern sources of cooking energy such as liquefied petroleum gas (LPG), and lighting energy such as electricity or solar home systems, as some of these households incur

[6] Hence, the incidence of energy affordability is equal to one minus the incidence of energy poverty, vice versa.

[7] This threshold was first estimated in the UK, based on the energy consumption requirements of households using data of the English housing survey and considered three (3) basic services: heating, lighting and cooking (Hills, 2012).

[8] For more detailed discussions on other energy poverty measures see Herrero (2017) and the references therein; and for general discussion on 'expenditure-based' indicators see also Churchill et al. (2020).

[9] The use of traditional energy also exposes household members to health and safety challenges (Lelieveld et al., 2015; Sovacool et al., 2016). Hence, including non-internalized externalities, such as effects of indoor smoke exposure, safety issues, as well as forest degradation, and the impacts of greenhouse gas emissions and climate change on human health, which in turn affects productivity and income (Chakravarty and Tavoni, 2013; World Bank, 2004), is quite important. This aspect of affordability, however, is often assessed within other criteria of energy justice, including the availability principle (which comprises a 'safety' sub-criterion) and intragenerational equity criterion. Moreover, such analysis requires empirical data that are currently not available (Sovacool et al., 2017).

[10] The statutory minimum monthly wage for each country is obtained from ILO (2021) and PRB (2014). It is 40,000 LCU for Benin, 55,000 LCU for Senegal and 35,000 for Togo.

[11] Crucially, however, there exist several activities that the household members perform for which market does not exist, especially in rural locations (Sharma, 2013). Hence, accounting for unemployment rate tends to discount the opportunity cost – due to the forgone time allocation to un-marketable (but, equally important) home production activities, such as child care activities and home cleaning among others – of household members who may potentially be unemployed. In fact, their involvement in such activities may lead to significant time gains for other members to be invested in productive activities.

[12] Again, in some households, the task of fuel collection is likely to be assigned to members with the least ability to earn market wage. Specifically, children are likely to participate in energy purchase or collection to ease the time constraint of adult household members, enabling them to allocate more time to other activities. Although this strategy would adversely affect children's time allocation to educational activities, and thus, be inefficient in the long-run, for poor households, it is often the most efficient in the short run.

[13] For modern lightning energy (e.g., solar lighting system), the opportunity costs correspond to the additional energy-related expenditure of the household as a result of the trip made by household members to pay monthly/weekly/daily fee to the company.

additional costs by making a trip to pay for lighting services at the operating companies or travel to refill their domestic LPG cylinders. However, 'zero' opportunity costs are recorded, for instance, in cases where such services are purchased via mobile payment methods (i.e., mobile money) and when adult household members are able to access cooking energy without having to go out of their homes or family compound[14].

4. Data

The study relies on primary data collected in rural Benin, Senegal and Togo, by local research institutions in collaboration with the national statistical institutes in each country. The surveys were funded under the project titled: "Optimal Strategies for Energy Efficiency for Rural Women's Energy Justice and Low-carbon Development" funded by the International Development Research Centre (IDRC) and implemented by the firm Econoler in 2019. Given the notable prevalence of traditional fuel consumption and its related inconveniences among the rural households compared with those in urban areas, in each country, the aim of the survey was to collect data that are representative of the rural population nationwide.

A stratified sampling method is used. It consists of partitioning each country into large geographical regions consistent with the existing administrative divisions. Two-stage sampling design is performed, with the selection of clusters from these regions at the first stage, based on the list established by national censuses. At the second stage, households were selected randomly. During the data collection stage, each household was visited by a team of two surveyors. A supervisor was assigned to each group to ensure that the methodology was respected. The questionnaires were administered to the head of the household. In case the head was absent after two attempts, the spouse was interviewed. The data were gathered from 640 rural households in Benin, 1000 in Senegal, and 650 in Togo, covering 14 regions in Senegal, and 3 regions and 12 departments in Benin and 5 regions in Togo. The datasets contain information on household characteristics (social, economic, demographic), electrification programs, availability of fuel and household energy consumption, and so on.

Similar to existing evidence in the context of developing countries, a vast majority of rural households in Benin, Senegal and Togo use traditional energy sources for cooking (Kaygusuz, 2010). As shown in Table 2, in the three countries, over 75% of rural households use fuelwood as their main source of cooking energy. Charcoal is the next dominant energy source with about one out of ten households using this fuel as their main cooking energy. While LPG is rarely used in rural Benin, and Togo, a relatively higher proportion of households use this source of cooking energy in rural Senegal: 3.8% in Senegal versus 0.5% and 0.9%, respectively in Benin and Togo (Table 2). With respect to lighting energy, nearly 33.8% and 14.2% of households in rural Senegal use electricity and solar domestic lighting system as a primary source of lighting, respectively. Meanwhile, the respective shares are 19.9% and 11.0% in rural Benin, and 18.0% and 4.2% in rural Togo. Additionally, kerosene wick lamps are the second dominant lighting sources in rural Benin (22.9%). This energy source is, however, among the least used in rural Togo (2.9%) and Senegal (0.3%).

In a vast majority of rural households, women are in charge of the collection of cooking fuel (between 81.7 and 100.0%). Since these households mainly rely on traditional biomass – which entails high drudgery – women tend to suffer most from the hardship of fuel collection. This finding is consistent with the existing evidence that fuel collection for cooking is a predominantly female-activity, with women bearing the difficulties of the task (Kanagawa and Nakata, 2007). Yet, men and children are also involved in this activity either regularly or occasionally. With respect to the main source of cooking energy, firewood, the respective shares of households that reported the participation of children and men in fuel collection are 53.6% and 50.6%. Conversely, adult male household members seem to be more involved in the purchase of lighting energy than female, except in households using kerosene wick lamps. In the latter, children and women are the main participants. This difference in members' participation across energy types is likely attributable to the division of labor within the household, with women mostly taking on cooking of family meals and fuel management activities (Ilahi, 2000; World Bank, 2004).

On average, households in rural Senegal are larger, with higher number of children, than their Beninese and Togolese counterparts (Table 3). The respective averages of household size are 13.5, 8.5 and 6.1. Household income is lowest in rural Togo and highest in rural Senegal, ranging from 1000 to 1,334,170 LCU in rural Benin, 1000 to 1,500,000 LCU in rural Senegal, and 2000 to 572,000 LCU in rural Togo. Furthermore, compared to Benin and Togo, Senegal has the highest minimum wage rate (wage per hour) and rural unemployment rates (378.6 LCU and 3.1%, respectively). Meanwhile, in Benin and Togo, the respective minimum wage rates (rural unemployment rates) are 244.1 LCU (1.2%), and 227.5 LCU (1.8%).

In the Senegalese sample, nearly half of the rural households reported that members do not have to go out of their homes to access lighting energy, as compared with 23.5% in Benin and 18.6% in Togo. With respect to cooking energy, however, the proportions of households with indoor access to fuel are 6.0% in rural Senegal and 0.5% in rural Benin. In most households, the trip to collect or purchase fuel is done on foot. The use of motorcycle, bicycle or car as a means of transportation is recorded in relatively higher shares of households in rural Benin and Togo. Meanwhile in rural Senegal, animal traction is the second dominant means for transportation (8.2 and 24.7% for lighting and cooking, respectively).

On average, household members in rural Senegal spend more time on fuel purchase or collection than their Beninese and Togolese counterparts: 62.9, 37.5 and 39.7 h a month, respectively. In addition, households in rural Benin travel on a smaller distance compared to their counterparts in rural Senegal and Togo: 52.3 km compared with 55.7 and 63.0, respectively. These observed differences in the time spent and the distance travelled for energy collection are presumably attributable to the heterogenous climatic conditions in these countries as well as the differences in the means of transportation. For instance, Senegal is dominated by arid and semi-arid climates, where vegetation is mainly grassland and fuelwood is relatively scarce thereby necessitating relatively greater amount of time for fuel gathering than their Beninese and Togolese counterparts (FAO, 1985). Furthermore, compared to rural Senegal and Togo, there is notable involvement of children in fuel collection or purchase in rural Benin. Children primarily bear the task in nearly 40% of rural households for lighting energy and 11% for cooking energy (Table 3).

5. Results and discussion

5.1. Opportunity costs of energy consumption in rural Benin, Togo and Senegal

As shown in Table 3, households in rural Benin record the lowest opportunity costs, while their Senegalese counterparts have the highest, on average. In rural Benin, this finding is presumably explained by the relatively low amount of time spent on fuel collection and the notable involvement of children in fuel collection. The average opportunity costs of energy consumption are 7225 LCU in rural Benin, 8663 LCU Francs in rural Togo, and 16,790 LCU in rural Senegal. Overall, the opportunity costs of energy consumption range from zero, to about 8 to 11 times the country averages. In per capita terms, the estimated opportunity costs are 1083 LCU in rural Benin, 1658 LCU in rural Togo, and 1554 LCU in rural Senegal (Table 4). These estimates of per capita opportunity costs

[14] These households include those in which adult members are rarely involved in fuel collection and where children participate largely in this activity.

Table 2
Descriptive statistics by energy sources.

	Share of household using the type of fuel (%)			Women participating in fuel collection (% of households)	Men participating in fuel collection (% of households)	Children participating in fuel collection (% of households)
Type of fuel	Benin	Senegal	Togo			
Cooking energy[a]						
Fuelwood	79.8	75.5	83.2	92.2	50.6	53.6
Crop residue	1.3	1.5	4.3	92.2	43.1	56.9
Charcoal	18.5	12.6	10.8	81.7	48.0	32.9
Animal waste	0.0	6.5	0.2	100.0	24.2	68.2
Liquefied Petroleum Gas (LPG)	0.5	3.8	0.9	83.0	63.8	17.0
Woodchips	0.0	0.1	0.6	100.0	40.0	60.0
Sample size	634	1000	650	2269	2247	2237
Lighting energy[b]						
Electricity	19.9	33.8	18.0	40.7	81.7	21.8
Solar domestic lighting system	11.0	14.2	4.2	29.8	70.7	13.2
Solar lamp	6.3	5.8	1.8	34.9	76.9	28.4
dry-cell battery lamp	37.3	38.1	71.2	74.7	77.9	41.8
Kerosene wick	22.9	0.3	2.9	74.4	51.8	88.7
Other sources	2.7	7.8	1.8	67.3	77.6	34.9
Sample size	638	1000	650	2103	2133	2128

Note: The table is based on the entire sample (i.e., prior to the data cleaning and the computation of the various indicators). Other sources of lighting energy include phone torch light and others.
a. Primary sources of cooking energy are considered.
b. Primary sources of lighting energy are considered.

represent between 4 and 6% of the extreme poverty line[15]. On average, the collection of cooking energy entails the highest opportunity costs. In rural Benin, the average opportunity costs for cooking energy are nearly 13 times that of lighting energy. Meanwhile, in rural Togo and Senegal, the respective ratios are 10 and 5. Since, these households predominantly use traditional biomass for cooking (over 95% in the three countries), and women are mostly in charge of the collection of cooking energy in these locations, the opportunity costs for cooking energy are likely to reflect the forgone income of female household members as a result of biofuel consumption.

Furthermore, a comparison of the share of opportunity costs in household income across countries suggests that, on average, Senegal has the lowest share of opportunity costs, followed by rural Benin and Togo. This finding is explained by the relatively higher income levels in Senegal. The respective shares of opportunity costs are 28.8%, 29.9% and 34.7%, suggesting that, on average rural households in West Africa could gain an additional 29 to 35% of their current income if household members access energy 'indoors' and the time used in fuel collection is allocated to income-generating activities. Compared to rural Benin and Togo, rural Senegal has a significantly higher concentration of the ratio around zero, suggesting that a larger proportion of households in rural Senegal have 'indoor' access to cooking and lighting energy (Table 4).

5.2. Energy affordability in rural Benin, Senegal and Togo

Table 5 reports the measures of energy affordability across countries and the levels of energy poverty derived from the affordability measure. The incidence of energy affordability is measured as the share of households whose energy expenditure as a percentage of total household income does not exceed the threshold, defined as: 10% for total expenditure on primary cooking and lighting energy sources, 5% for cooking and 5% for lighting energy (ESMAP, 2015; Boardman, 1991). For each threshold, the affordability measure is calculated using the household energy expenditure *excluding* and *including* the estimated opportunity costs. The latter gives a better picture of energy affordability since it reflects the full costs of energy (monetary and non-monetary). The findings suggest that overall, the incidence of energy affordability (energy poverty) – measured at the 10% threshold – is highest (lowest) in rural Senegal, followed by rural Benin and Togo, respectively. Thus, energy is most affordable for rural households in Senegal and least affordable in rural Togo (Table 5). While the ranking is consistent for cooking energy, lighting energy is more affordable in rural Togo than Benin.

Furthermore, the proportion of energy poor households is significantly higher when the opportunity costs of energy is controlled for than otherwise (Table 5). For instance, the shares of households whose expenditure on energy, excluding opportunity costs, is less than or equal to 10% are: 75.4%, 34.0% and 30.1% in rural Senegal, Benin and Togo, respectively. However, after taking the opportunity costs into account, the overall picture worsens, with a notable drop in the share of rural households using affordable energy, particularly in Senegal, where it falls by about 43.4 percentage points as compared to 16.6 points in Benin and 20.5 points in Togo, thereby reducing the gap in the relative shares across countries. In order words, by accounting for the time spent on fuel collection and the cost of transportation, the findings reveal that nearly 68.0% of households in rural Senegal are energy poor, compared to 82.6% in rural Benin and 90.4% in rural Togo[16].

5.3. Correlates of affordability in rural Benin, Senegal and Togo

To examine the correlates of energy affordability, Table 6 presents the average marginal effects of energy price, households' socio-economic characteristics, the type of energy used and rural electrification policy on the probability of using affordable energy. The dependent variable is dichotomous: taking the value '1' if the household is able to afford energy and '0' otherwise[17]. The analysis is performed using a Logistic regression model.

[15] This comparison is based on the international poverty line of US$1.9 per person a day. The conversion is done using the official exchange rate and the consumer price indices obtained from the World Development Indicators (WDI) (World Bank, 2021).

[16] Only primary sources of energy for cooking and lighting are considered in the estimations.

[17] The affordability measure considered in the regression analysis takes into account the opportunity cost of fuel use.

Table 3
Selected households' characteristics and mean of transportation to energy sources.

	Benin	Senegal	Togo		Benin	Senegal	Togo
Household size				Age of household head			
Mean	8.5	13.5	6.1	*Mean*	46.4	51.2	46.5
Std. Dev.	6.0	8.2	2.9	*Std. Dev.*	13.5	14.7	15.1
Min	2.0	2.0	1.0	*Min*	19.0	18.0	19.0
Max	53.0	70.0	18.0	*Max*	111.0	98.0	100.0
Number of children				Monthly minimum wage per hour (LCU)			
Mean	4.4	7.0	3.2	*Mean*	244.1	378.6	227.5
Std. Dev.	4.1	4.9	2.2	*Std. Dev.*	0.0	0.0	0.0
Min	0.0	0.0	0.0	*Min*	–	–	–
Max	36.0	40.0	10.0	*Max*	–	–	–
Household income (Total; LCU)				Unemployment rate – Rural (%)			
Mean	70,645.4	110,723.4	52,732.6	*Mean*	1.2	3.1	1.8
Std. Dev.	127,879.7	97,631.8	55,008.0	*Std. Dev.*	0.0	0.0	0.0
Min	1000.0	1000.0	2000.0	*Min*	–	–	–
Max	1,334,170.0	1,500,000.0	572,000.0	*Max*	–	–	–
Time spent by household members on purchasing fuel per month (Total; Hours)				Distance travelled by household members to collect or purchase fuel per month (Total; km)			
Mean	37.5	62.9	39.7	*Mean*	52.3	55.7	63.0
Std. Dev.	51.9	81.6	40.4	*Std. Dev.*	66.4	79.4	65.0
Min	0.0	0.0	0.0	*Min*	0.0	0.0	0.0
Max	344.0	606.7	316.0	*Max*	424.0	796.0	416.0
Monthly transportation cost for lighting energy (Total; LCU)				Monthly transportation cost for cooking energy (Total; LCU)			
Mean	132.7	43.6	125.2	*Mean*	225.3	37.9	72.4
Std. Dev.	411.3	249.1	529.3	*Std. Dev.*	796.8	475.6	564.5
Min	0.0	0.0	0.0	*Min*	0.0	0.0	0.0
Max	3000.0	3000.0	8000.0	*Max*	9260.0	9800.0	6980.0
Extent of children participation in household fuel collection/ purchase for lighting (%)				Extent of children's participation in household fuel collection/ purchase for cooking (%)			
Mainly	39.7	5.2	2.8	*Mostly*	10.7	4.9	4.0
Equally	0.0	0.0	0.0	*Equally*	0.0	0.0	0.8
Not at all or little	60.3	94.8	97.2	*Not at all or little*	89.3	95.1	95.2
Total	100	100	100	*Total*	100	100	100
Means of transportation to lighting energy source (%)				Means of transportation to cooking energy source (%)			
By bicycle	1.6	1.1	3.5	*By bicycle*	2.0	1.1	1.1
By car	0.0	3.4	0.8	*By car*	2.3	1.0	0.3
On foot	60.5	34.4	67.4	*On foot*	66.7	65.5	92.8
By motorcycle	13.5	1.0	8.7	*By motorcycle*	21.6	0.5	3.7
Animal traction	0.0	8.2	0.0	*Animal traction*	1.3	24.7	0.9
Other means	0.9	0.4	1.0	*Other means*	5.6	1.2	1.1
None	23.5	51.4	18.6	*None*	0.5	6.0	0.0
Total	100.0	100.0	100.0	*Total*	100.0	100.0	100.0
Sample size*	607	989	642	Sample size	607	989	642

Notes: The minimum wage is computed by dividing the monthly minimum wage for each country by the average number of hours worked by the working population. The data on minimum wage are obtained from ILOSTAT, ILO (2021) and PRB (2014). The rural unemployment rates are from ILO (2021). The Local Currency Units (LCU) are CFA Francs (average 2019 official exchange rate 1USD ≈ 585.95 LCU). *The overall sample size is reported.

Table 4
Opportunity costs of energy use by country.

	Benin		Senegal		Togo	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Monthly opportunity cost (Total; LCU)	7225.1	11,635.7	16,790.1	22,554.5	8663.0	8983.9
Monthly opportunity cost per capita (Total; LCU)	1082.8	1950.3	1554.4	2417.1	1657.8	1797.5
Monthly opportunity cost - Cooking (Total; LCU)	6692.6	11,354.6	13,874.0	19,478.1	7856.2	7992.3
Monthly opportunity cost - Lighting (Total; LCU)	532.4	1804.2	2916.1	10,356.2	806.8	2982.4
Share of opportunity cost in household income (%)	29.9	66.8	28.8	54.9	34.7	60.4
Share of households with no opportunity cost (%)	9.1		16.4		7.5	
Sample size*	607		989		642	

Notes: The opportunity cost of energy is measured as the opportunity cost incurred by the household as a result of the time spent by household members and the cost transportation. It is computed using data on the monthly minimum wage, the average number of hours worked by the working population, and the unemployment rate in rural arears in Benin, Senegal and Togo. The data are obtained from ILOSTAT, ILO (2021) and PRB (2014). The Local Currency Units (LCU) are CFA Francs (average 2019 official exchange rate 1USD ≈ 585.95 LCU). *The overall sample size is reported. For the share of opportunity cost in household income, the sample sizes are 586, 978 and 635 for Benin, Senegal and Togo, respectively.

As shown in Table 6, in Senegal, energy is significantly less affordable in female-headed rural households than male. This finding is likely attributable to the relatively high incidence of income poverty among female-headed households than male (UNECA, 2017). The result is in line with the findings of Ismail and Khembo (2015), who also found that female headship is associated with energy poverty in the South Africa. Furthermore, rural households headed by a person with primary education or more are more likely to afford energy and be energy non-poor than those whose head does not have formal education. The coefficients are significant for Benin and Senegal, suggesting that having a formal education contributes to the adoption of more affordable energy sources than otherwise (Behera et al., 2015). Also, in all three countries, an additional adult member increases the probability that the household would afford its energy consumption, implying that adult household

Table 5
Energy affordability across countries.

	Benin		Senegal		Togo	
	Affordability (%)[a]	Energy poverty (%)[b]	Affordability (%)[a]	Energy poverty (%)[b]	Affordability (%)[a]	Energy poverty (%)[a]
Threshold = 10%						
Without opportunity cost	34.0	66.0	75.4	24.6	30.1	69.9
With opportunity cost	17.4	82.6	32.0	68.0	9.6	90.4
Threshold = 5% – Cooking energy						
Without opportunity costs	37.4	62.6	76.4	23.6	27.4	72.6
With opportunity costs	15.9	84.1	28.5	71.5	6.6	93.4
Threshold = 5% – Lighting energy						
Without opportunity costs	47.4	52.6	76.2	23.8	59.2	40.8
With opportunity costs	41.5	58.5	64.8	35.2	50.1	49.9

Notes: The indicators are computed using the share of energy expenditure in total household income. Households' primary sources of energy for cooking and for lighting were considered.
a. The share of households whose energy expenditure as a percentage of total household income is less or equal to the threshold.
b. The share of households whose energy expenditure as a percentage of total household income is greater than the threshold

Table 6
Logit regression estimates: Correlates of affordability (Average marginal effects) – Dependent variable: Affordability dummy (at 10% threshold).

Variables	Benin	Senegal	Togo
Female head	0.01	−0.09**	−0.03
	(0.31)	(−2.33)	(−0.90)
Head has primary education or more	0.06**	0.08**	−0.04
	(2.45)	(2.25)	(−1.39)
Number of adult members	0.02***	0.01***	0.02**
	(3.46)	(2.75)	(2.47)
Number of children	0.00	0.00	0.02**
	(0.84)	(0.69)	(2.72)
Log of fuelwood price		−0.02	0.01
		(−1.18)	(0.29)
Household uses electricity/solar energy as the main source for lightning energy	0.03	0.06**	0.06**
	(0.85)	(1.96)	(2.42)
Household uses LPG as the main source of cooking energy	0.07	−0.01	−0.01
	(0.57)	(−0.16)	(−0.06)
Rural electrification program over the last 5 years (Ref. =No)			
Yes	0.02	0.02	0.01
	(0.55)	(0.60)	(0.28)
Don't know	0.09*	−0.04	−0.04
	(1.86)	(−0.74)	(−1.35)
Availability of traditional biomass in the area	0.11**	−0.01	−0.07**
	(2.27)	(−0.10)	(−2.38)
Income group (Ref. = Low income)			
Middle income	0.12***	0.10***	0.05***
	(3.89)	(2.97)	(3.59)
High income	0.36***	0.32***	0.25***
	(10.74)	(8.49)	(6.87)
Observations	555	968	635
Pseudo R2	0.23	0.08	0.22

Robust t-statistics in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note: The estimation accounts for sample design.

members are more likely to contribute to family resources, and hence, enable the household to meet its energy needs. An additional child increases the chance that a household would afford energy, thereby enabling rural households in Togo to escape energy poverty. This result is likely attributable to the reduction in the household's expenditure on energy owing to children involvement in fuel gathering in rural Togo.

As expected, greater access to modern lighting energy, such as electricity and solar energy, increases the chances that a household would afford energy, particularly in rural Senegal and Togo. The findings imply that, for rural households, using modern lighting energy is relatively less expensive. Also, it would presumably free up time for household members – particularly women – which could be devoted to income generating and productive works, including non-market production activities (e.g., agricultural production for household consumption), thereby increasing household welfare. Meanwhile, there seems to be no significant differences in the probabilities to afford energy between rural households that use LPG and those that do not. Furthermore, rural electrification programs seem to have played little role in the overall energy affordability for rural households, although households that benefited from such programs might have witnessed a reduction in opportunity cost (Table 6).

The availability of biomass energy is likely to affect the probability of energy poverty either positively or negatively. On the one hand, it may lower the energy expenditure share of income, as households are able to access traditional biofuel free of charge or at a low price, thereby making the fuel relatively more affordable. On the other hand, it could increase the share of opportunity costs in total income, since households would be more likely to adopt biomass energy and spend time collecting fuel, and thus decreasing the probability of affordability. Consequently, the overall effect of woody biomass availability on energy poverty is likely to depend on the local context. As shown in Table 6, while Togolese households living in areas where traditional biomass is available are more likely to be energy poor than those residing in areas where that resource is scarce, the reverse is the case in rural Benin. Thus, in rural Togo, the availability of traditional energy sources in the area of residence seems to be an incentive factor in the use of biomass energy, which tends to require higher amount of time and effort for collection (Table 6).

Lastly, high income increases the probability of accessing affordable energy. The finding corroborates that of Khandker et al. (2012) who show that increasing income is crucial to ensure energy affordability and alleviate energy poverty in India. This result is partly attributable to the fact that members of poorer households are likely to endure higher inconveniences – and thus higher opportunity cost – to meet their energy demand. This situation could create a vicious cycle between energy poverty and income poverty. In other words, due to income poverty, household members would presumably spend more time and effort to collect or purchase traditional fuel to meet basic energy needs, and by so doing forgo substantial income which could help them escape income poverty.

6. Conclusion

Affordability is an important criterion for energy justice globally, and particularly in regions with high energy poverty levels where energy access is far from being universal. Achieving this criterion not only presupposes that modern and reliable energy is available at an adequate price, but also requires that socio-economic and demographic characteristics of the households enables them to access these energy sources. In the developing world, particularly in rural areas, affordability seems to be one of the primary factors influencing the households' energy choice (Behera et al., 2015). Yet, measuring the cost of energy goes beyond the price of the fuel to include other non-monetary costs, such as the time spent for energy collection, which could be allocated to human capital development, economic opportunities and income-generating activities. While in the developed world, these non-monetary costs are close to zero, this is not always the case in developing countries, especially in rural areas where they usually befall women and children. This study, therefore, sought to operationalize and evaluate energy affordability using a broader approach, which captures the monetary and non-monetary costs of energy consumption, both affecting the capabilities of households' members. The analysis focuses on rural dwellings in West Africa. Three representative countries are considered, namely, Benin, Togo and Senegal.

The results suggest that, on average, the opportunity costs related to energy collection represent between 29 and 35% of household income. The average monthly opportunity cost of energy consumption per person ranges from 1083 to 1658 LCU, the highest being recorded in rural Togo and the lowest in rural Benin. These estimates represent approximately between 4 and 6% of the international extreme poverty line of US $1.9 per person per day. The collection of cooking energy, which is mainly from traditional sources – namely, fuelwood, crop residue, charcoal, etc. – entails the most drudgery, and thus generates significantly higher opportunity cost than lighting energy. These types of energy are predominantly collected by women, who are traditionally in charge of cooking the family meals. Additionally, a significant decline in the share of households that are effectively able to afford energy is observed once the opportunity cost of energy is taken into account. Thus, the findings show that failing to account for non-monetary costs of energy consumption in rural locations leads to a wrong categorization of nearly 17 to 43% of the sample as energy non-poor, when in fact these households spend substantial amount of time in fuel collection and members often need to walk long distances to gather fuel. These estimates should however be considered as lower-bound values for rural locations in the three countries, since the estimated opportunity cost does not include broad social costs such as the risks involved (e.g., the exposure of women and girls to physical abuse, etc.) nor the health effects of biomass fuel collection or use (e.g., carrying physical loads that are unhealthy in size and quantity, indoor air pollution, etc.), particularly for female-household members, nor the climate change impacts.

The study further analyses the correlates of energy affordability across countries. Overall, the results reveal that households that adopt modern energy sources tend to afford energy compared with their counterparts that use traditional lighting energy. Thus, providing better access to modern energy sources should remain the key priority of policy makers in rural West Africa. Nevertheless, while rural electrification programs might have helped reduce the opportunity costs for households, they seem to have no significant effect on the probability that a household would afford energy, and escape energy poverty. This finding suggests that supplying electricity alone does not guarantee access and may not suffice in reducing energy poverty in rural areas. In fact, the results also show that an increase in households' income would promote energy affordability in rural Benin, Senegal and Togo. Thus, rural electrification programs should be accompanied by job creation and other social interventions for greater affordability and higher adoption of electricity as a main source of energy. Furthermore, consistent with other existing studies, the analysis reveals that female empowerment is not only a means to reduce energy poverty in rural areas, but would also be a consequence of access to modern energy in rural West Africa.

Lastly, the above findings focus on rural households in West Africa, which are energy poorer than urban households, on average. Furthermore, the opportunity costs of energy use related to fuel collection are generally more salient in rural areas. And the socioeconomic conditions of urban and rural areas can be quite different. Hence, the estimates provided in this analysis do not reflect the situation in urban West Africa where opportunity costs of energy consumption are expected to be lower. This issue, however, falls outside the scope of this paper and could be an important research area for future studies.

Credit author statement

All the three authors hold the seniority of the paper. We all have worked on the conception. Aklesso and Laurent contributed to the data collection and treatment. Dede has carried out the econometric estimations and all of us have contributed to the writing of the manuscript.

Acknowledgments

This article is an outcome of the project titled "Optimal strategies of energy efficiency for low carbon emission development"- Project number 6156. The project is funded by the IDRC through ECONOLER. The authors wish to thank IDRC and ECONOLER for financial support. The authors thank specifically Dr. Laurent Jodoin and all the other team members that have worked to fulfill the goals of this project, and the two anonymous reviewers for helpful comments.

Appendix A. Descriptive statistics of data used in estimating the correlates of energy affordability

Table A1 presents the summary statistics of the sample used in the analysis of the determinants of energy affordability. Overall, energy is more affordable in rural Senegal than in rural Benin and Togo: 31.8% in the former versus 17.3% in rural Benin and 9.6% in rural Togo. On average, the numbers of adult household members and children are highest in rural Senegal and lowest in Togo. Fuelwood is over 5 times more expensive in rural Senegal than in rural Togo, on average, reflecting the relative scarcity of that source of cooking energy, presumably as a result the climatic conditions in the former. Furthermore, most household heads have no formal education in rural Senegal (79.3%), while in Benin and Togo over 50% of rural households are headed by a person with primary education or more. Also, male-headed households represent over 80% of the Senegalese and Togolese samples and nearly 90% of total households in rural Benin.

Rural Togo, however, recorded the largest share of female-headed households (18.1%), followed by rural Senegal (16.4%) and rural Benin (8.8%). Consistent with existing evidence, access to modern energy is more prevalent in Senegal, which is also among the countries with the highest electrification rate in West Africa. As shown in Table A1, about 47.7% of households in rural Senegal use modern sources of energy (solar and electricity) for lighting compared to 31.9% in rural Benin and 22.5% in rural Togo. Similarly, with respect to cooking energy, the respective shares of households that utilize Liquefied Petroleum Gas (LPG) are 3.8%, 0.5% and 0.9% in rural Senegal, Benin and Togo. Furthermore, nearly 26.3% of households in rural Benin reported that they benefited from a rural electrification program over the last 5 years, as compared to 29.6% and 22.5% in rural Senegal and Togo, respectively. Given the climatic differences between countries – Senegal belongs to the Sahelian region with semi-arid grasslands, while Benin and Togo are predominantly humid coastal countries – over 90% and nearly 77.3% of households in rural Benin and Togo, respectively, reported that traditional biomass is largely available in their area of residence. In rural Senegal, however, the presence of biofuel is reported by 66.7% of total households.

Table A1
Descriptive statistics: Determinants of energy affordability.

Variables	Benin	Senegal	Togo
Affordable energy			
No	82.7	68.2	90.4
Yes	17.3	31.8	9.6
Number of adults			
Mean	4.1	6.4	2.8
Std. dev.	2.9	4.4	1.5
Min	1.0	1.0	1.0
Max	27.0	40.0	9.0
Number of children			
Mean	4.5	7.0	3.2
Std. dev.	4.3	4.9	2.2
Min	0.0	0.0	0.0
Max	36.0	40.0	10.0
Price of fuelwood			
Mean		217.9	38.2
Std. dev.		173.4	37.6
Min		28.0	6.0
Max		483.5	271.3
Female head			
No	91.2	83.6	81.9
Yes	8.8	16.4	18.1
Head has primary education or more			
No	49.2	79.3	39.4
Yes	50.8	20.7	60.6
Household uses electricity/solar energy for lightning			
No	68.1	52.3	77.5
Yes	31.9	47.7	22.5
Household uses LPG for cooking			
No	99.5	96.2	99.1
Yes	0.5	3.8	0.9
Rural electrification program over the last 5 years			
Yes	26.3	29.6	22.5
No	59.8	63.3	66.8
Don't know	13.9	7.0	10.7
Availability of traditional biomass in the area			
No	8.8	33.3	22.7
Yes	91.2	66.7	77.3
Income group			
Low income	31.7	33.6	34.6
Middle income	34.2	33.1	31.7
High income	34.1	33.4	33.7
Total	100	100	100
Sample size	555	968	635

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