

International Journal of Global Energy Issues

ISSN online: 1741-5128 - ISSN print: 0954-7118

<https://www.inderscience.com/ijgei>

Energy technology efficiency influence on energy poverty and energy justice in West African households

Evrard Karol Ekouédjen, Safiou Bouraima, Gaston Ganhoun, Latif Adéniyi Fagbemi

DOI: [10.1504/IJGEI.2025.10067978](https://doi.org/10.1504/IJGEI.2025.10067978)

Article History:

Received:	05 July 2022
Last revised:	10 November 2023
Accepted:	18 December 2023
Published online:	16 December 2024

Energy technology efficiency influence on energy poverty and energy justice in West African households

Evrard Karol Ekouédjen*

Unité de Recherche en Valorisation Energétique de la Biomasse,
Laboratoire d'Energétique et de Mécanique Appliquée (LEMA) de
l'Ecole Polytechnique d'Abomey-Calavi,
Université d' Abomey-Calavi,
West Africa, Benin, Abomey-Calavi, Cotonou, Benin
and
Sustainable and Fair World ONG,
Cotonou, Benin
Email: ekouedjen92@gmail.com
*Corresponding author

Safiou Bouraima and Gaston Ganhoun

Unité de Recherche en Valorisation Energétique de la Biomasse,
Laboratoire d'Energétique et de Mécanique Appliquée (LEMA) de
l'Ecole Polytechnique d'Abomey-Calavi,
Université d'Abomey-Calavi,
West Africa, Benin, Abomey-Calavi, Cotonou, Benin
Email: boursafiou@gmail.com
Email: dubosganhoun@gmail.com

Latif Adéniyi Fagbemi

Unité de Recherche en Valorisation Energétique de la Biomasse,
Laboratoire d'Energétique et de Mécanique Appliquée (LEMA) de
l'Ecole Polytechnique d'Abomey-Calavi,
Université d'Abomey-Calavi,
West Africa, Benin, Abomey-Calavi, Cotonou, Benin
and
Sustainable and Fair World ONG,
Cotonou, Benin
Email: latiff08@yahoo.fr

Abstract: This paper presents a new indicator which measure energy poverty (as energy justice component) called Modified Energy Poverty Index (MOEPI). It is a composite index and developed based on United Nations Human Development Index (HDI) methodology. MOEPI defines energy poverty as three dimensions conjunction: excessive energy inconvenience, energy deficit and equipment energy (in)efficiency. It captures energy deficit effect on education and include energy acquisition cost in energy inconvenience assessment. MOEPI is implemented on a sample of

640 households in Benin. Results showed 65.15% energy poor households surveyed. Energy poor are divided into three sub-groups, slightly energy poor (6%), moderate energy poor (53%) and severe energy poor (41%). Energy deficit and equipment energy inefficiency are the main dimensions responsible for household energy poverty. An improvement in equipment energy efficiency resulted in a 32.02% decrease in the number of energy poor households.

Keywords: energy efficiency; energy poverty; energy justice; index; energy deficit; energy inconvenience.

Reference to this paper should be made as follows: Ekouédjen, E.K., Bouraima, S., Ganhoun, G. and Fagbemi, L.A. (2025) 'Energy technology efficiency influence on energy poverty and energy justice in West African households', *Int. J. Global Energy Issues*, Vol. 47, Nos. 1/2, pp.88–126.

Biographical notes: Eyvart Karol Ekouédjen holds a doctorate in energy efficiency and renewable energy from the University of Abomey-Calavi in Benin. He is a member of the energy and applied mechanics research laboratory (LEMA), and also of the energy research department of the NGO Sustainable and Fair World (SF World). He teaches in the mechanical and energy engineering department of the Ecole Polytechnique d'Abomey-Calavi (EPAC) in Benin. He has over six years' experience in scientific research into renewable energy and energy efficiency.

Safiou Bouraima is a graduate of the University of Abomey-Calavi in Benin, specialising in energy efficiency and renewable energies. He is a member of the energy and applied mechanics research laboratory (LEMA). He teaches in the Department of Mechanical and Energy Engineering at the Ecole Polytechnique d'Abomey-Calavi (EPAC) in Benin. He has over six years' experience in scientific research into renewable energy and energy efficiency.

Gaston Ganhoun is a graduate of the University of Abomey-Calavi in Benin and specialises in energy and environment. He is a member of the energy and applied mechanics research laboratory (LEMA). He teaches in the Department of Mechanical and Energy Engineering at the Ecole Polytechnique d'Abomey-Calavi (EPAC) in Benin. He has over seven years' experience in scientific research into renewable energy and energy efficiency.

Latif Adéniyi Fagbemi is a graduate of the Université Technologique de Compiègne in France and the University of Abomey-Calavi in Benin, specialising in energy and the environment. He is a member of the energy and applied mechanics research laboratory (LEMA) and head of the biomass energy recovery unit. He is also Honorary President and Senior Energy Advisor of the NGO SF World. He teaches in the Department of Mechanical and Energy Engineering at the Ecole Polytechnique d'Abomey-Calavi (EPAC) in Benin, and has over 35 years' experience in teaching and scientific research in renewable energy and energy efficiency in Benin.

1 Introduction

Energy is indispensable for human life, and development is unattainable without it. It stands as a crucial tool in realising Millennium Development Goals (Tombofa and Tombofa, 2013). SDG7 strives to guarantee universal access to dependable, affordable,

sustainable and modern energy services for all (UN Energy, 2005). That goal can't be achieved without advocating for access to sustainable and cost-effective energy (Garba and Bellingham, 2021; Sy and Mokaddem, 2022). However, there are inequalities in energy access around the world. Millions of people in the world live without access to clean energy. In 2021, about 770 million people could not access electricity, nearly 75% of them (570 million) from Sub-Saharan Africa (Ye and Koch, 2021; SDG 7, 2022; Hosan et al., 2023). Nearly 2.6 million people worldwide (about 35% of the world's population) lack access to modern cooking energy sources (WEO, 2017; Hosan et al., 2023). Inequalities in access to clean and affordable energy sources are predominantly prevalent in Africa, Asia and South America. Over two-thirds of the global population lacking access to electricity presently resides in sub-Saharan Africa (International Energy Agency, 2019). Energy justice argues for equitable distribution of benefits and advantages stemming from energy services and systems, as well as fostering more inclusive decision-making (Jenkins et al., 2016). Energy justice is a complex and multidimensional phenomenon, of which energy poverty is one dimension (Halff et al., 2014). Researchers defined energy poverty as a core component of energy justice (Jenkins et al., 2016; Bouzarovski, 2017). At its essence, energy poverty is a complex issue rooted in distributive injustice, and this is compounded by other injustices in the realms of recognition and policy-making procedures (Walker and Day, 2012). It affects developing countries, mainly those in sub-Saharan Africa (Nguyen and Su, 2022). In 2019, approximately 850 million individuals in sub-Saharan Africa rely on wood energy (biomass) as their primary source of cooking energy (International Energy Agency, 2019). Energy poverty affects vulnerable populations in sub-Saharan Africa much more. For example, household air pollution is associated with approximately half a million premature deaths annually. These premature deaths are attributed to non-access to clean, sustainable and affordable cooking facilities, and this affect more adversely women and children (International Energy Agency, 2019). In Benin, a recent study revealed that firewood (76.48%) and charcoal (18.18%) are the main cooking energy sources for households. They use dry non-rechargeable batteries (34.78%) and paraffin lamps (24.70%) for electricity and lighting needs (Fagbemi et al., 2020). The study reveals that approximately 79% of surveyed households fall into energy poverty based on Boardman's economic approach (Boardman, 1991).

Defining and implementing policies to reduce energy poverty and improve energy justice require a clear definition and measurement criteria. Energy poverty definition varies significantly between developed and developing countries (Siksnyte-Butkiene et al., 2021; Gafa and Egbendewe, 2021). Energy poverty measurement tools are manifold and varied. Several approaches are used in literature to quantify household energy poverty. Lot of them define energy poverty as lack of access to modern energy sources in developing countries (International Energy Agency, 2019; Modi et al., 2005) and as households high energy cost and as households' incapacity to afford essential energy requirements, including heating, cooking, lighting and cooling (Sy and Mokaddem, 2022; Che et al., 2020; Betto et al., 2020; Barrella et al., 2022). The key issue is to identify which energy poverty indicator to apply for a given region because of its relevance to that region realities. Nussbaumer et al. (2012), Mirza and Szirmai (2010), IEA (2010), Maxim et al. (2016) and Karmaker et al. (2022) used for energy poverty measurement. The question is "which kind of energy poverty is measured?". Most energy poverty indicators used to assess energy poverty in developing countries are settled on developed countries realities basis, which are not always those of developing countries in sub-

Saharan such as Benin. Better still, the criteria defined in these indicators do not fit to any Sub-Saharan Africa reality and thus bias measurements made and resulting analyses. For example, an energy consumption threshold is estimated at 156.55 kWh weekly per person (Karmaker et al., 2022). This estimate is not realistic in Benin, where weekly energy needs are far below this threshold because there is no need for house heating. In developing countries, energy poverty is more closely associated with energy inconveniences, the lack of availability of minimum energy needed for basic energy needs or lack or poor efficiency of technologies than to the lack of access to modern energy. A high household energy poverty score may be related to household equipment energy inefficiency. It is therefore important that energy poverty measurement should consider households equipment energy efficiency. Numerous studies have demonstrated that most households experiencing energy poverty depend on equipment that is either inefficient or ineffective (Fagbemi et al., 2020; Pachauri et al., 2004; Boemi and Papadopoulos, 2020). Energy poverty measure must be able to show this relationship. Therefore, energy poverty indicators specific to sub-Saharan African countries and true to African realities are needed to assess household energy poverty level of in sub-Saharan Africa. Energy poverty indexes can be broadly categorised into three main types: One-Dimensional Indices, a set of individual indicators or dashboards and composite indexes. The first category of index is easy to handle, give an unbiased information for a specific dimension and offer easy calculation but they are not suitable for multidimensional phenomenon such as energy poverty. Dashboards offer a complete representation of studied problem but are complexes to be implemented, tracking trends over time is difficult and comparison between countries is not possible. The last category is made of composite indexes which are simple figures, simple to calculate but are sometimes misleading when analysis becomes overly simplistic or inadequate when the indicator is mis constructed (Khanna et al., 2018; Nussbaumer et al., 2012; Gafa and Egbendewe, 2021; Mirza and Szirmai, 2010). This work focuses on developing a composite index that considers energy poverty as the result of three dimensions including energy technologies efficiency, energy mix inconvenience and energy deficit.

This paper thus develops a new approach of energy poverty measurement in rural households in Sub-Saharan Africa with an application to Benin's case. The new indicator developed, makes possible to consider real studied households minimum energy needs, households' energy technologies efficiency and to integrate education and energy acquiring costs into energy poverty measurement. This paper is organised in four parts. The first part introduces the problem and places it in context and describes the study objectives. The second section provides a comprehensive literature review of various existing indicators used to measure energy poverty, highlighting their strengths and limitations. The third section outlines newly proposed indicator and details used database. The last part presents and discusses indicator implementation results.

2 Literature review

A universally accepted and standardised definition for energy poverty does not exist (Halff et al., 2014; Salk et al., 2020; Che et al., 2020; Siksnyte-Butkiene et al., 2021). It is a multidimensional phenomenon (Nussbaumer et al., 2012). In this section, we describe existing energy poverty indicators. There are 03 categories of energy poverty indicators: unidimensional indices or individual indicators, non-aggregated sets of

individual indicators or 'dashboard' and composite indices (Nussbaumer et al., 2012). Unidimensional indices are easy to handle, provide unbiased information for a specific dimension and are easy to interpret with simple calculations (Bersisa, 2016; Nussbaumer et al., 2012; Foster et al., 2000). Nevertheless, they offer a limited perspective on the issue and are unsuitable for addressing problems of a multidimensional nature. Included in this category is Boardman economic approach proposed in 1991 (Boardman, 2012) which asserts that a household falls into the category of energy poverty if it allocates more than 10% of its income to energy expenses (Johansson and Goldemberg, 2002).

The second category is that of non-aggregated individual indicator sets or "dashboards". This type of indicator provides a comprehensive representation of the problem under study but is complex in tracking trends over time and cross-country comparisons are not possible. In this category we find Energy Indicators for Sustainable Development (EISD), created by IAEA (2008), represents one instance. In the same category, is two-dimensional assessment of energy poverty and energy distribution put forth by Pachauri et al. (2004). Energy Access Ecosystem Index (Practical Action, 2014) includes 9 indicators equally divided between policy, finance, and capacity. It is a set of individual indicators. Each indicator is rated from 0 to 3 based on a set of qualitative criteria. The index assesses the potential, i.e., national ability to move towards universal energy access. It does not reflect status of energy access in a country but highlights obstacles and opportunities that lie in the way of change. It allows different stakeholders to see where significant changes are needed and in that it holds governments to account. It can be used in an annual reporting process at national level. Additionally falling into this category is Household Energy Poverty Index (HEPI), devised in India by Gupta et al. (2020). HEPI utilises unit-level data from the national sample survey and incorporates a robust set of 15 key energy indicators that span various dimensions of energy. Weights for these indicators are determined through Principal Component Analysis (PCA). Another contribution is Energy Poverty Multidimensional Indicator System proposed by Che et al. (2020), which employs 11 indicators related to energy availability, energy affordability and energy cleanability to offer a comprehensive perspective on energy poverty.

The last category of indicators comprises composite indices, constituting most indicators. These composite indices serve as a middle ground between unidimensional indicators simplicity and necessity to consider certain issues multidimensional nature, as energy poverty (Nussbaumer et al., 2012). These indices are single values derived from multiple variables, capturing the aggregate value of a single dimension that may be challenging to grasp (as seen in the case of sustainable development) constructed upon a foundational model. However, they can be misleading if analysis is overly simplistic, or indicator is mis constructed. Within this category, one notable example is Energy Development Index (EDI) (IEA, 2010). EDI, designed to parallel UNDP HDI, comprises four indicators, each of which represents a specific aspect of potential energy poverty:

- Commercial energy consumption per capita: serves as an indicator of a country's overall economic development;
- Electricity consumption per capita in residential sector: an indicator of electricity services reliability and consumers' ability to pay;

- Share of modern fuels in total residential energy consumption: serves as an indicator of the level of access to clean cooking facilities;
- Share of population with access to electricity.

An individual index is established for each indicator, utilising observed maximum and minimum values within the scope of developing countries considered. Each indicator performance is quantified as a value ranging from 0 to 1, computed using provided formula below as formula (1). Subsequently, Energy Development Index (EDI) is derived as arithmetic mean of these four values for each country.

$$\text{Indicator} = \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}} \quad (1)$$

Within this category, we also encounter Energy Poverty Index (EPI) introduced by Mirza and Szirmai (2010). This index considers drawbacks of employing various energy sources within a household, as well as absence of such sources. Additionally, it factors in household size. Energy poverty is caused by two (02) factors:

- The substantial inconvenience linked to rural households' energy mix.
- Energy insufficiency to fulfil fundamental household requirements (referred to as the energy deficit).

As an innovative feature, EPI integrates existing measures of energy deficit with assessments of drawbacks associated with traditional energy sources utilisation. Energy inconvenience denotes the extent of physical challenges in obtaining and utilising an energy to fulfil household energy needs. To quantify these challenges, following indicators are identified:

- Energy collecting frequency;
- Travelled distance for energy collection;
- Type of transportation used for energy collection;
- Household member involvement in energy acquisition;
- Weekly energy collection spent time;
- Household health;
- Participation of children in energy collection.

This indicator is assessed in seven (07) steps and is developed following HDI methodology.

Multidimensional Energy Poverty Index (MEPI) is a composite index introduced by Nussbaumer et al. (2012). Diverging from other instruments, MEPI concentrates on measuring energy deprivation rather than emphasising energy access. Several indices incorporate consumption-based indicators under the assumption that consumption correlates with development. Authors, however, have restricted the focus of this study exclusively to household needs, acknowledging the existence of additional energy requirements for societal development and prosperity. Common energy services essential for households encompass:

- Cooking;
- Space heating/cooling;
- Lighting;
- Amusement;
- Services provided by household appliances;
- Communication and mechanical energy.

MEPI's method is drawn from OPHI methodology (Alkire and Foster, 2008). It comprises 5 dimensions that represent fundamental energy services, encompassing a total of 6 indicators. Scores allocated to various indicators are outlined in Table 1. An individual is categorised as energy poor if the cumulative deprivations surpass a predetermined threshold. MEPI is computed as headcount ratio product (proportion of individuals identified as energy poor) and the average intensity of deprivation among energy poor.

Table 1 Energy poverty dimensions for MEPI (Nussbaumer et al., 2012)

<i>Dimension</i>	<i>Indicator (Weight)</i>	<i>Variables</i>	<i>Deprivation cut-off (energy poor if ...)</i>
Cooking	Modern cooking fuel (0.2)	Type of cooking fuel	The use of any fuel, excluding electricity, LPG, kerosene, natural gas or biogas.
	Indoor pollution (0.2)	Cooking done on a stove or open fire without a hood or chimney, indoors, qualifies if any fuel is utilised other than electricity, LPG, natural gas or biogas.	True
Lighting	Electricity access (0.2)	Has access to electricity	False
Services facilitated through household appliances, including entertainment and education.	Household appliance ownership (0.13)	Has a fridge	False
	Entertainment/education appliance ownership (0.13)	Has a radio OR television	False
Communication	Telecommunication means (0.13)	Has a phone land line OR mobile phone	False

Following this, numerous indicators have come to light. In the realm of composite indices, there exists energy poverty index introduced by Bonatz et al. (2018). This index, among the most recent, delineates and contrast China energy poverty with Germany's one over previous decade. It incorporates indicators related to access and affordability, elucidating recent low-carbon development strategies and their impacts on energy

efficiency and production. The index underscores linkages between energy poverty and sustainable development, pinpointing opportunities and impediments in addressing energy poverty.

The primary causes of energy poverty for many authors revolve around energy availability, accessibility and affordability. Nevertheless, existing energy poverty assessments do not consistently encompass all three factors simultaneously. In response to this, a new indicator for gauging energy poverty has emerged. Termed Comprehensive Energy Poverty Index (CEPI), this composite index, proposed by Khanna et al. (2018), assesses energy poverty scope in ASEAN countries and India, considering three aforementioned factors. Among surveyed nations, Cambodia exhibits the highest degree of energy poverty, while Thailand ranks as the least energy poor. Table 2 provides a summary of various energy poverty indicators most encountered in the literature.

Table 2 Overview of primary energy poverty indicators

<i>Index categories</i>	<i>Index</i>	<i>Authors</i>	<i>Strengths</i>	<i>Weakness</i>
One-dimensional Indices	Foster et al. Index	Foster et al. (2000)	• Easy to handle • Unbiased information for a specific dimension	• Narrow view of the problem • Not suitable for problems of a multidimensional nature
		Siksnyte-Butkiene et al. (2021)	• Easy calculation • Easy interpretation • Can be adapted to national standards • Other human needs are considered	
Set of individual indicators or dashboards	Two-dimensional measurement	Pachauri et al. (2004)	• Complete representation of the problem studied	• Complexes to be implemented • Tracking trends over time is difficult • Comparison between countries not possible
	IEDD HEPI energy access ecosystem index energy poverty multidimensional indicator system	IAEA (2008) Gupta et al. (2020) Practical Action (2014) Che et al. (2020)		

Table 2 Overview of primary energy poverty indicators (continued)

<i>Index categories</i>	<i>Index</i>	<i>Authors</i>	<i>Strengths</i>	<i>Weakness</i>
Composite indexes	EDI	IEA (2010)	• Simple calculation	• Sometimes misleading when analysis is too simplistic or when the indicator is poorly constructed
	EPI	Mirza and Szirmai (2010)	• Single figure	
	MEPI	Nussbaumer et al. (2012) and Gafa and Egbendewe (2021)	• Simple to implement	
	EPI	Bonatz et al. (2018)		
	CEPI	Khanna et al. (2018)		

3 Construction of modified energy poverty index (MOEPI)

The indicator we propose is a composite index that modifies the one proposed by Mirza and Szirmai (2010). The approach employed for gauging energy poverty in households across Sub-Saharan Africa utilises Human Development Index (HDI) methodology.

MOEPI proposes that in addition to energy mix inconvenience and energy deficit, household equipment energy efficiency should be considered. This index considers household size influence. Energy poverty is therefore determined by three (03) dimensions:

- Significant inconvenience linked to rural households' energy mix.
- Inadequate energy to fulfil essential household needs (energy deficit).
- Equipment energy (in) efficiency.

Energy inconvenience pertains to the extent of physical challenges involved in collecting and utilising energy sources. As a novel feature, it integrates established measures of energy poverty with assessments of inconveniences linked to traditional energy sources use, considering equipment energy efficiency. Modified Energy Poverty Index (MOEPI) integrates three new indicators in addition to the 7 proposed by Mirza and Szirmai (2010) in energy inconvenience assessment of (see Table 3).

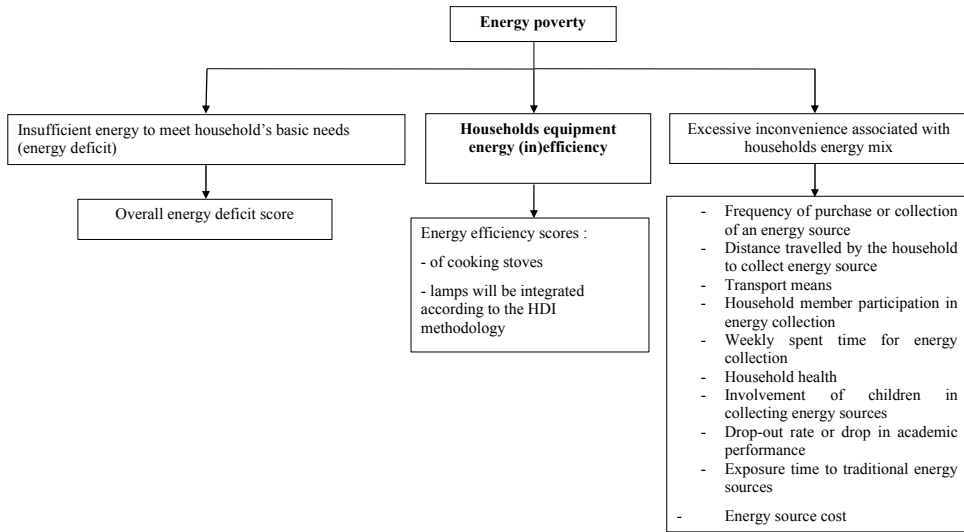
Thus, ten (10) parameters are used for energy inconvenience assessing. Indeed, the drop-out rate or decrease in academic performance are included to inform negative impacts on education that energy deficit could cause. Oum (2018); Kumar (2018); Yadava and Sinha (2019); WHO (2009); Wagner et al. (2017); IEA (2010) and Karmaker et al. (2022) shown that energy deficit negatively affects learners' academic performance in rural areas. In addition, time of exposure to traditional energy sources provides important information on health risks faced by household members. Finally, energy source cost price provides information on supply hardship, as it includes transport cost of and/or energy source purchase price. All of these provide information on the degree of physical difficulty in accessing energy and seem relevant for inclusion in indicator implementation. Figure 1 summarises MOEPI structure and Table 4 presents the summary of energy inconvenience parameters.

Table 3 Comparison between EPI and MOEPI

<i>Rubrique</i>	<i>EPI Mirza and Szirmai (2010)</i>	<i>MOEPI</i>
Dimensions determining household energy poverty	• Substantial inconvenience related to energy mix in rural households. • Insufficient energy to meet household's basic needs (energy deficit)	• Significant inconvenience linked to energy mix in rural households. • Insufficient energy to fulfil fundamental household needs (energy deficit). • Equipment energy (in)efficiency
Indicators of energy inconvenience or discomfort	• Frequency of energy source purchase or collection of an • Distance travelled • Transport means • Participation of household member in energy acquisition • Time spent collecting energy source • Household health • Involvement of children in collecting energy sources.	• Frequency of energy source purchase or collection • Distance travelled • Transport means • Participation of household member in energy collection • Weekly spent time for energy collection • Household health • Children's participation in energy source collection • School drop-out rate or decline in academic performance • Time of exposure to traditional energy sources • Energy cost

Table 4 Summary of parameters s of energy inconvenience

<i>Energy inconvenience parameters</i>	<i>References</i>
• Frequency of energy source purchase or collection	Mirza and Szirmai (2010)
• Distance	Mirza and Szirmai (2010)
• Transport mean	Mirza and Szirmai (2010)
• Household member participation in energy collection	Mirza and Szirmai (2010)
• Weekly spent time for energy collection	Mirza and Szirmai (2010)
• Household health	Mirza and Szirmai (2010)
• Involvement of children in collecting energy sources.	Mirza and Szirmai (2010)
• Drop-out rate or drop in academic performance	Oum (2018); Yadava and Sinha (2019); Kumar (2018); WHO (2009) and Karmaker et al. (2022)
• Exposure time to traditional energy sources	
• Energy source cost	

Figure 1 Overview of the modified energy poverty index (MOEPI)

Modified Energy Poverty Index (MOEPI) calculation involves energy deficit assessment. For this purpose, a minimum energy needed to meet basic energy needs definition is required.

3.1 Definition of the minimum energy needed for a household

Households' energy deficit assessing require, establishing a minimum energy level necessary to fulfil basic needs. This section assesses the minimum energy required to meet a household basic energy needs. According to Salk et al. (2020) and Reddy et al. (2009), basic energy needs are mainly related to heating (cooking) and lighting (Half et al., 2014). However, increasingly it is considered that electricity, cooking energy as well as mechanical energy are needed for household welfare (Modi et al., 2005; International Energy Agency, 2018). For other authors, the minimum energy package for basic needs should include at least several light bulbs, should be able to charge phones, and should run a radio and possibly a fan or television (International Energy Agency, 2019). However, in developing countries such as most of Sub-Saharan Africa, including Benin, energy concerns are different. Energy needs at grassroots level are mainly devoted to heating (cooking) and lighting. Poor countries energy landscapes are clearly different from those of developed countries. In that countries, fans, refrigerators and televisions are luxuries that people can do without. Socio-cultural realities offer alternatives to people in terms of access to information and entertainment, notably palaver trees and griots, etc. We are not saying that modern energy technologies are not useful but that they are not indispensable. On this basis, we will try to define the minimum energy level required for a household in a sub-Saharan developing country. To this end, several studies have been carried out. According to Reddy et al. (2009), required energy for cooking is about 2.3 GJ per capita per year. Author goes on to state that electricity for lighting, fans, etc., would be about 18 Watts per capita per year. This leads him to a total of about 91 Watts per capita per year, which is finally rounded up to 100 W per capita

per year. In Guatemala, Foster et al. (2000) recommends that a household should be capable of operating two 60-watt light bulbs and a 16-watt radio for four hours daily. Furthermore, household should be able to use five two-kilogram firewood logs each day for cooking. According to the same source, this establishes an energy poverty threshold of 2154 kilowatt-hours per year (5.9 kilowatt-hours per day). However, this approach does not consider equipment energy efficiency. For example, two 60 W bulbs may not provide required visual comfort to individuals due to lamps poor luminous efficiency. A more interesting approach would be to use normative measurements to assess energy requirement. On the other hand, some literature proposes that a per capita energy consumption of 1.0 to 1.2 kW allows a score of 90 on Physical Quality of Life Index (Goldemberg et al., 1985). Other authors propose an energy consumption of about 1 kW per capita per day (Goldemberg, 1990). In a report on energy demand modelling in India from 1984 (ABE, 1984) cited in Pachauri et al. (2004), the Advisory Board on Energy assumed that approximately 30W of useful energy per capita was necessary to fulfil cooking energy requirements. In a 1984 report on energy demand modelling in India (ABE, 1984) cited in Pachauri et al. (2004), the Advisory Board on Energy assumed that about 30W of useful energy per capita was required to meet cooking energy needs. According to the same source, it is specified that 1.5 W of useful energy per capita per year is needed to meet basic energy requirements for domestic lighting and an additional 1.5 W for space heating. In essence, summarily, this approach asserts that 33 Watts per capita per day are necessary to fulfil basic energy needs. These different approaches allow us to understand that basic energy needs evaluation is an uneasy and rather complex task, and it would therefore be impossible to evaluate it with precision (Goldemberg, 1990). On the other hand, we consider that most of these assessments are subjective and do not necessarily correspond to Sub-Saharan Africa realities, including Benin. Indeed, the countries of Sub-Saharan Africa are located in tropical regions where it is not very cold, unlike countries in temperate environments. Therefore, basic energy needs assessment does not include habitat heating. We focus mainly on lighting and cooking (of food or heating water for various uses). It is important to understand that cooking habits differ from region to region, and this results in a difference in basic energy needs estimation for cooking. To this end, we introduce a new approach to measuring energy poverty for developing countries in sub-Saharan Africa described in this paper.

3.1.1 Estimation of minimum energy requirement for lighting

According to lighting standard EN 12464-1, illumination level should range from 300 lux to 500 lux for work areas, depending on the type of activity carried out there, and 300 for surrounding areas. We use illumination values average per heading. As illuminance level is known, we will deduce corresponding luminous fluxes. Indeed, illuminance describes the density of luminous flux at a point on a surface (formula (2) below):

$$E = \frac{\Phi}{S} \quad (2)$$

where:

E is illuminance in lux (lx)

Φ is lamp luminous flux in lumen (lm)

S is illuminated surface in (m^2).

A deduction of luminous flux gives: $\Phi = E * S$

Tolerated surfaces to obtain building permit in Benin, in accordance with Decree No. 2014-205 of 13 March 2014 regulating issuance of building permits in Benin Republic, are used to assess surface area of each house compartment.

According to Article 3 of Decree N° 2014-205 of 13 March 2014, habitable rooms are considered as habitable rooms, those rooms which are intended for the day and night accommodation of one or more persons and which are used for rest, pleasure, meals and activities of their usual occupants. It stipulates that habitable rooms must have a surface area of at least 9 m^2 with a ceiling height of 2.4 m or more. This surface should be at least 12 m^2 in the case of a single room. For a living room, this minimum will be 16 m^2 . Excluded from surface area calculation of habitable rooms, are surfaces of cupboards, wardrobes or storage rooms opening onto these rooms.

For example, we assume that kitchens must have a minimum surface area of 9 m^2 . For living room, an area of 20 m^2 is chosen. A surface of 12 m^2 is recommended for bedroom. On this basis, assess required light flows and lamps to be installed power.

To realise SDGs, LED lamps are increasingly being used in all countries. As we assess basic energy needs, we prioritise three areas for domestic lighting: kitchen, living room (lounge) and bedroom. The following Table 5 summarises different assessments made.

Table 5 Lighting requirements by house compartments

Type of room	Required average illumination level (EN 12464-1) in lux	Level of illumination retained (lux)	Minimum surface area (m^2)	Corresponding luminous flux (lumen)
Kitchen	200–500	350	9	3 150
Living room	50–200	125	20	2 500
Bedroom	100–200	150	12	1 800
Total	–	–	–	7 450

LED lamps luminous efficiency range from 30 to over 200 lumen/Watt. We take 120 lm/W as an average energy efficiency (the purpose of the estimation is to find the minimum energy level required). With this luminous efficiency, we estimate lamp power required for each aspect of lighting. Recall that luminous efficiency is given by the following formula (3):

$$E_l = \frac{\Phi}{P} \quad (3)$$

with:

E_l is luminous efficiency (lm/W)

Φ is luminous flux (lm)

power (W)

A formula (4) is used to deduct power:

$$P = \frac{\Phi}{E_l} \quad (4)$$

Corresponding energy is determined by multiplying power by operating time. Thus, daily energy required for lighting is assessed. A survey (Fagbemi et al., 2020) of 640 households in 120 villages in 22 communes in 6 departments of Benin, located mainly in rural areas but also in urban and peri-urban areas, revealed that an average of 23.75 hours per week is spent cooking meals in households. On average, households dedicate 3.4 hours per day cooking meals.

Table 6 Average time spent cooking meal per day

<i>Average (hour)</i>	<i>Variance</i>	<i>Std. Dev.</i>
23.75	207.46	14.40

As there is no local statistical data on the average time spent in living room and in bedroom, we make the following assumptions. According to local habits and traditions, adults in households spend their days at work (or in the field) and children at school (or in the field when they are not in school). The time spent in living room is therefore shorter on weekdays than at weekends. Nevertheless, we retain an average of 5 hours per day spent in Livingroom. As regards the time spent in bedroom to sleep, it should be noted that this is relative. Some people sleep with lights on but others do not. We therefore suggest an average of 5 hours per day of lighting in bedroom. Table 7 below summarises the determination of the minimum energy for lighting.

Table 7 Minimum lighting energy determination

<i>Type of room</i>	<i>Corresponding luminous flux (lumen)</i>	<i>LED luminous efficiency (lumen/Watt)</i>	<i>Power (Watt)</i>	<i>Operating time (hours)</i>	<i>Daily energy in (Watt-hour)</i>
Kitchen	3 150	120	27	3.4	92
Living room	2 500	120	21	5	105
Bedroom	1 800	120	15	5	75
Total	8 500	120	–	–	272

For an average household in Benin (5.2 members according to National Institute of Statistics and Demography – INStAD) (INSAE, 2018), about 272 Watt-hours are required for basic lighting energy needs per day.

3.1.2 Minimum cooking energy requirement estimation

The minimum energy needed for cooking varies significantly with household size. The minimum energy required to cook meals varies greatly depending on household size but also on community culinary habits, on region or country. In Benin, e.g., voandzou (*Vigna subterranea*) and beans are very popular meals but take a long time to cook. On average, voandzou takes 2 to 3 hours to cook and beans 1 hour, although these values vary according to cooked species. Another difficulty lies in diversity of cooking energy sources, this adds complexity to evaluating minimum cooking energy requirement task. In addition, the type of pot used and cookstove are factors that influence required energy for cooking, not to mention pressure and environment weather conditions. We suggest considering average cooking energy consumption surveyed as minimum energy requirement for cooking. This approach enables to offer a flexibility to indicator, making it possible to be used in any country, region or environment. Indeed, as cooking realities

are relative to setting, it would be inappropriate to impose a minimum level of cooking energy for all users of the indicator regardless of their different realities. By offering users the possibility of integrating energy consumption average for cooking measured in their surveys, our indicator is therefore adaptable to any environment. Thus, based on surveys of 640 households in Benin, household cooking energy consumption average is 2.14 kWh per day per household. This score therefore represents the minimum energy required for cooking per day per household for proposed indicator.

Synthesis: Previous sections allowed to find a minimum energy requirement of 272 Watt-hours per day per household for lighting and a minimum of 2.14 kWh per day per household for cooking. This leads to a minimum total energy use of 2.412 kWh per day per household, which we round up to 2.42 kWh. This amounts to 466 Watt-hours (equivalent to 0.47 kWh) per day per capita for Benin.

3.2 *Equipment energy (in) efficiency assessment grid*

In this section, a summary of household's different equipment energy efficiencies is presented. These are mainly wood and/or charcoal stoves and lamps energy efficiency. Table 8 below presents the energy efficiency (in) assessment grid for the equipment used.

Table 8 Grid for assessing equipment energy (in) efficiency

<i>Designation</i>		<i>Efficiency (% for cooking stoves) and lumen/Watt for lamps</i>	<i>Reference</i>
Wood-burning cooking stove	Three stones	15	Ochieng et al. (2013)
	In traditional Nansu clay (improved)	18	WEO (2017)
		31	WEO (2017)
Charcoal cooking stove	Traditional	23	WEO (2017) and Ekouedjen et al. (2020)
	In clay (traditional)	23	WEO (2017)
	Nansu (improved)	32	WEO (2017)
Gas cookers	Traditional gas stove	32	WEO (2017)
	Gas cooker	50	WEO (2017)
Electric cooker		50	
Lamps	LED	80	REEEP (2009)
	Solar lantern	45	REEEP (2009)
	Dry battery torch	50	REEEP (2009)
	Rechargeable battery lamp	60	REEEP (2009)
	Domestic solar system	50	REEEP (2009)
	oil-powered	2	Nieuwenhout et al. (2014)
	Compact fluorescent lamps	60	REEEP (2009)

3.3 Energy inconvenience measurement

3.3.1 Means of transport used to collect energy

Energy inconvenience associated with house-holds energy collection transport means is presented in Table 9.

Table 9 Inconvenience scores for transportation means (Mirza and Szirmai, 2010)

	1	2	3	4	5	6	7
Transportation Means	tractor	cart (animal)	car	public transport	motorbike	bicycle	by foot

3.3.2 Household members involvement

Table 10 grid is used to assess the indicator relating to household members involvement in the collection, purchase and transport of a particular energy source.

Table 10 Inconvenience scores for household involvement (Mirza and Szirmai, 2010)

	1	2	3	4
Household Involvement	Only 1 member	2 members	3 members	More than 3 members

3.3.3 Household health and children's participation in energy source collection assessment

To compute household health index, a score of 0 is assigned if the household members do not have respiratory or visual health problems, while a score of 1 is assigned if they do (see Table 11).

Table 11 Energy disadvantages related to children's health and involvement (Mirza and Szirmai, 2010)

Score	0	1	2
Health issue	No issue	Health issue	
Children participation	No participation	Limited participation	Full participation

To assess children's involvement in energy collection indicator, household is given a score of 0 if no children are involved in collection, a score of 1 if there is partial involvement of children in collection, and a score of 2 if there is full involvement of children (see Table 11).

3.3.4 Grid for assessing drop-out or decline in academic performance

Energy deficit impacts of on education are mainly manifested in reduced academic performance which can lead to learners dropping out of school. Indeed, not having access to light energy in the evenings to study prevents learners in households without access to electricity from studying at night. Yet during the day on working days they are in school to receive lessons. The time they have for study is during the day in their spare time or at weekends if they are not busy with field work. The time spent studying is already reduced because of the lack of light energy at night, and is further reduced if learners are

involved in collecting energy sources. They lose time collecting energy sources by travelling for miles. This time could have been used to study. It should be noted that some households use paraffin lamps for lighting after dark and their learners take advantage of this to study. This solution certainly addresses part of the problem but exposes learners to visual and respiratory health problems. According to INSAE (2018), almost half (48%) of the household population in Benin is made up of children under the age of 15. On this basis, there are about 2.5 children per household. We then propose the following grid (see Table 12) to assign scores representing school dropout or decline in academic performance for a household.

Table 12 Education grid

<i>Number of children out of school or whose academic performance has declined</i>	<i>Evaluation</i>	<i>Score</i>
3 or more	Very poor	3
2	Poor	2
1	Fair	1
None	Best	0

3.4 Modified energy poverty index (MOEPI) calculation

Modified Energy Poverty Index calculation involves 11 steps described in this section.

Step 1: Computing the inconvenience index for each inconvenience indicator

The inconvenience indicators mentioned above are closely tied to the number of household members, i.e., the size of the household. To address this, we set three (03) inconvenience indicators related to household size. These indicators include:

- How often an energy source is bought or collected
- Participation of the household member in energy source acquisition
- Weekly spent time for energy source collection

When household size increases, more energy source collecting time is required. We proceeded to normalise the scores for these indicators by dividing them by the number of household members, thereby adjusting for the influence of household size. The remaining indicators remain unaffected by household size.

Using Human Development Index (HDI) method (Nations Unies, 1990), the index computing formula is as follows (see formula (5)):

$$X_{hij} = \frac{R_{hij} - R_{ij}(\min)}{R_{ij}(\max) - R_{ij}(\min)} \quad (5)$$

where

As household size R is the score of the response to an energy disadvantage question; h identify the household; i indicates inconvenience indicator, j indicates the energy source; min for minimum and max for maximum rates for indicators i and j , respectively.

Step 2: Computation of the energy inconvenience index for a determined energy source

Following the previous step, we compute the global energy discomfort by energy source j as an unweighted average of the separate inconvenience indices.

$$EII_{hi} = \frac{\sum_{i=1}^n X_{hij}}{N_{ij}} \quad (6)$$

where EII_{hi} is the energy disadvantage index for a type of energy j in household h . N represents the amount of relevant disadvantage indicators for a single energy source. For traditional biomass, e.g., $N = 7$; for paraffin, $N = 6$; for LPG, $N = 5$.

Utilising average of disadvantage indices offers the advantage of compensating for the high complexity of one type of indicator with a low disadvantage on another indicator.

Step 3: Calculation of the global energy disadvantage index (TEI_h)

We assess the household disturbance index TEI_h by aggregating the inconvenience indices and weighting them by energy source share (in kWh) in household energy mix.

$$TEI_h = \sum_{j=1}^6 \frac{Kw_{hj}}{\sum Kw_{hj}} * EII_{hj} \quad (7)$$

TEI_h is the household h global energy disadvantage indicator considering its energy. The ratio $\frac{Kw_{hj}}{\sum Kw_{hj}}$ represents an energy source j share in kWh in the household's global energy consumption in kWh.

Step 4: Establishing the Overall Energy Inconvenience Threshold (TEIT)

To examine energy poverty, it is essential to establish the severity threshold, the Total Energy Inconvenience Threshold (TEIT), exceeding which a household is classified as energy poor due to the significant inconvenience linked to its energy mix. The inconvenience limit is determined as total energy inconvenience average. In the surveyed sample, the total energy inconvenience average (TEIT) is set at 0.22.

The threshold for energy discomfort is set at a value of 0.22. When the disadvantage falls below this level, it is deemed acceptable for rural households. However, surpassing this threshold signifies a degree of disadvantage that categorises the household as experiencing fuel poverty.

Step 5: To analyse energy poverty, a threshold definition is needed for excess energy disadvantage (EIE) computation at household level

At this step, energy discomfort grades are transformed into a percentage of the threshold, allowing for a better interpretation of the index values. The extent of inconvenience above the threshold (TEIT) is referred to as Excess Energy Convenience (EAC), and it is computed as follows (see formula (8)):

$$EIE_h = \frac{TEIT - TEI_h}{TEIT} * 100 \quad (8)$$

EIE_h Is a %. A negative sign signifies that rural households are experiencing an excessive level of disturbance, meanwhile, a positive sign suggests that households are in a state of ‘convenience’.

Step 6: Computation of households Energy Shortfall (ES)

$$ES_h = \frac{AEC_h - TER}{TER} * 100 \quad (9)$$

ES_h is the energy deficit of household h ; AEC_h is the actual household energy consumption (in kWh); Total Energy Requirement (TER) is the required energy per household in kWh. The TER is a threshold value in kilowatt-hours (kWh), indicating a level below which an individual lacks sufficient energy and is classified as experiencing energy poverty. We estimate the TER by using engineer-type calculations, and on the basis of the basic energy needs, we calculate a threshold that represents the lowest level of energy consumption needed for a household.

TER is determined previously and is worth 2.42 kWh/day/household. This amounts to 466 Watt-hours (equivalent to about 0.47 kWh) per day per capita for Benin. This indicator is expressed per capita for comparison purpose.

To ensure comparability between the energy poverty index and the energy deficit index, where the same sign signifies energy poverty, the authors subtracted the Total Energy Requirement TER from the household's Adjusted Excess Convenience AEC_h instead of the reverse. Consequently, negative values represent a household's energy deficit.

Step 7: Energy efficiency index computation by type of energy source for the household X_{hj}

Using the HDI methodology (United Nations, 1990), the main formula for computing the index is as follows:

$$X_{hj} = \frac{E_{hj} - E_j(\min)}{E_j(\max) - E_j(\min)} \quad (10)$$

with

E is the energy efficiency score; h represents the household; j is the type of energy; min and max are for minimum and maximum grades for determined fuel j .

Step 8: Computation of household total energy efficiency index (TEF_h)

We compute TEF_h aggregating efficiency indices for all the sources of energy j used by household h , and assigning weights based on source proportion (in kilowatt-hours) in the household total energy consumption.

$$TEF_h = \sum_{j=1}^6 \frac{Kw_{hj}}{\sum Kw_{hj}} * X_{hj} \quad (11)$$

TEF_h the household h total energy efficiency index depending on its specific energy. The quantity $\frac{Kw_{hj}}{\sum Kw_{hj}}$ represents the share of energy in kWh of an energy source j in the household's overall energy consumption in kWh.

Step 9: Defining Total Energy Efficiency Threshold (TEFT)

To analyse energy poverty, energy efficiency threshold definition is important, Total Energy Efficiency Threshold (TEFT), exceeding this point, a household is categorised as energy inefficient for the poor energy efficiency of its equipment. TEFT is set at the average value of total energy efficiency. This value in the surveyed sample is 0.55. The TEFT is then taken equal to:

$$TEFT = 0.55 \quad (12)$$

$TEFT$ represents energy efficiency threshold level. Below this level, house-holds energy efficiency is considered unacceptable as the household suffers from energy inefficiency. Above the threshold, the household's energy efficiency is acceptable.

Step 10: Energy efficiency gap (EEG) calculating at the household level

Energy efficiency grades are transformed in a threshold percentage so that a relevant interpretation can be given to the indicator values. The level beyond the threshold ($TEFT$) is called the Energy Efficiency Gap (EEG) computed as follows:

$$EEG_h = \frac{TEF_h - TEFT}{TEFT} * 100 \quad (13)$$

EEG_h is in %. A negative sign signifies that rural households are experiencing an excess of energy inefficiency, conversely, a positive sign suggests that households are in a state of 'energy efficiency'.

Step 11: Computation of the Modified Energy Poverty Index (MOEPI)

The last step is combining the previous three indicators (EIE_h, ES_h, EEG_h) in a single one, that represents the new energy poverty index for a given household. MOEPI is computed as the unweighted average of the three indicators mentioned above. Thus:

$$MOEPI_h = \frac{1}{3} * (EIE_h + ES_h + EEG_h) \quad (14)$$

$MOEPI_h$ provides the extent of energy poverty within a household on a per capita basis. Negative values denote energy poverty in a household, while positive values signify the absence of energy poverty.

3.5 Data description

Data are collected from a 640 households survey in Benin (Nguyen and Su, 2022). Most of surveyed households live in rural and peri-urban areas. The study covered 22 of

Benin's 77 cities, and 6 of the 12 regions were surveyed as shown on Figure 2. About 120 villages or city districts were surveyed, with a minimum of 5 households per village. In some villages, more than 5 households were surveyed, resulting in a total of 640 households surveyed. Villages, cities, regions selection as well as surveyed households' identification are carried out randomly (simple random choice). This sampling method is preferred because it allows for statistical inference. Villages or city districts are selected from the list of Benin villages (National Institute of Statistics and Demography – INSTAD). Survey was based on a representative sample of Beninese population. Energy access remains a major challenge for most Beninese. This challenge is more important in rural localities than urban ones. The sample studied therefore represents an interesting group for the authorities in charge of energy, the economy and the environment.

The questionnaire used is structured under four headings that provide information on general household information, access to electricity, clean cooking energy sources and cookstoves' technology used by households. Gender-energy issues are also discussed.

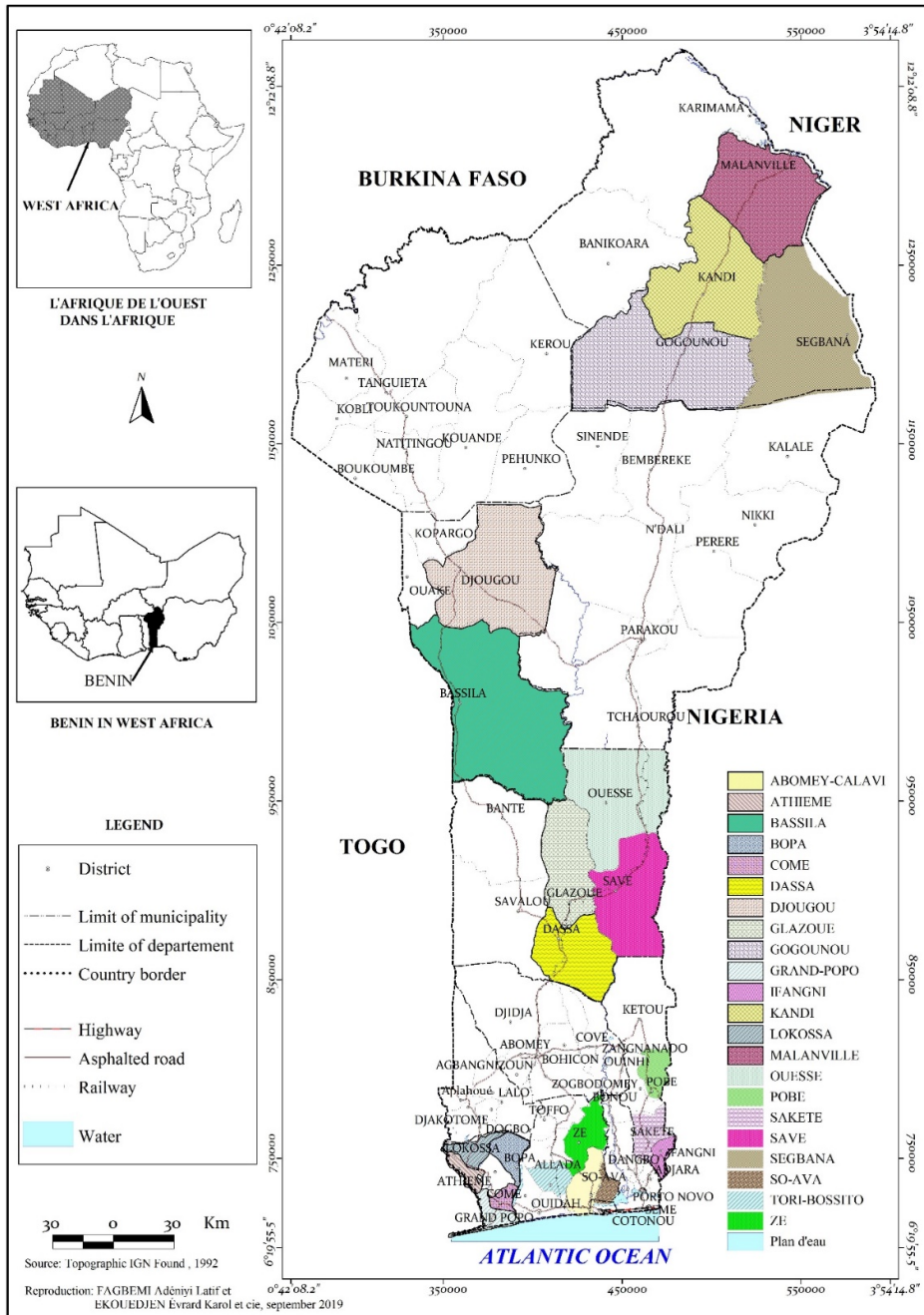
3.5.1 Target population description

This research focuses exclusively on households, encompassing both rural and urban settings. As per the 'Larousse' dictionary, a household, statistically speaking, is defined as the fundamental statistical unit of the population. It comprises one or more individuals (single individuals, families or communities) residing in the same dwelling as their primary residence. The household is examined in its economic consumption role. It is crucial to emphasise that, households with only one member or those without children are not included in this study.

3.5.2 Survey questionnaire description

The survey questionnaire is made of four sections. The initial section covers the socio-demographic features of the surveyed households. The second section outlines aspects such as access to electricity, household lighting, availability of cooking energy and types of cooking stoves used. The third section delves into energy policy considerations, and the final section addresses gender-related issues. Participation in inquiries regarding personal household information is voluntary, and households opting not to respond are under no obligation to do so. The surveys encompass both quantitative and qualitative dimensions. The quantitative section entails administering the questionnaire to households, while the qualitative aspect includes interviews with households, village groups, cooperatives and focus groups. While the findings of the qualitative component enhance a more profound comprehension of the quantitative data, they are not elaborated upon in this report.

Figure 2 Overview of the survey area (Fagbemi et al., 2020) (see online version for colours)



4 Innovative aspect of the method

First of all, MOEPI defines energy poverty as a function of three dimensions: energy deficit, inconvenience linked to household energy mix and household equipment energy efficiency. This approach makes it clear that the energy efficiency of equipment plays a key role in measuring energy poverty, something that has so far been omitted. The use of inefficient or poorly performing equipment significantly influences energy poverty measurement. This is therefore almost the first time that households' equipment energy efficiency is used as a variable to assess energy poverty. Combination of these three dimensions provides a more comprehensive understanding of energy poverty multifaceted character. The other important contribution is in energy-related inconvenience assessment. In addition to the 7 parameters proposed by Mirza and Szirmai (2010), we include education (indicated by school drop-out rate or academic performance drop), exposure time to conventional energy resources and energy expenses associated. These new parameters allow to better appreciate inconvenience associated with households' energy mixes.

Secondly, MOEPI's method is flexible. Indeed, users of this method have the possibility to adapt it to the realities of their study's environments. For example, cooking energy requirements threshold values vary greatly depending on environment in which one is located (country, region, etc.). Thus, the proposed indicator does not force the user of a given region to use cooking energy threshold values from another region with different climatic and culinary realities. This flexibility makes the proposed indicator valid for different regions.

Another contribution of this work is lighting lowest energy requirements setting based on international standards. In fact, the minimum requirements for visual comfort vary according to the type of activity carried out in the room to be lit, not according to the environment or country. For this reason, lighting energy requirement defining based on the minimum visual comfort requirements for house's main rooms has the advantage of meeting international requirements and once again makes method accessible to everyone.

To end, this study proposes an indicator which is one of the first to be developed for a West African country and that consider cultural, culinary and energy realities of the populations of sub-Saharan Africa. MOEPI better fit to African realities and will provide a better understanding of energy poverty in this region of the world. This method enables to better reflect households' energy face in developing countries.

5 Results and discussions

5.1 Results

5.1.1 Results of MOEPI implementation

MOEPI's implementation shows that out of 640 households surveyed, 417 households, i.e., approximately 65.15% of surveyed households, are energy poor. Among energy poor households, a classification has been established. Given that energy poverty is defined by three (03) dimensions, namely energy (in) efficiency, energy deficit and excessive inconvenience, we assume that three categories of energy poor households be distinguished:

- slightly energy-poor households with a single unfavourable score for all three dimensions;
- moderately energy-poor households scored unfavourably on two of the three dimensions;
- severely energy-poor households characterised by unfavourable scores for all three dimensions studied.

Figure 3 below shows the different categories of poor households and percentages that each category represents. There are 221 moderately energy poor households (53%), 171 severely poor households (41%) and 25 slightly poor households (6%).

Figure 3 Energy-poor household classes

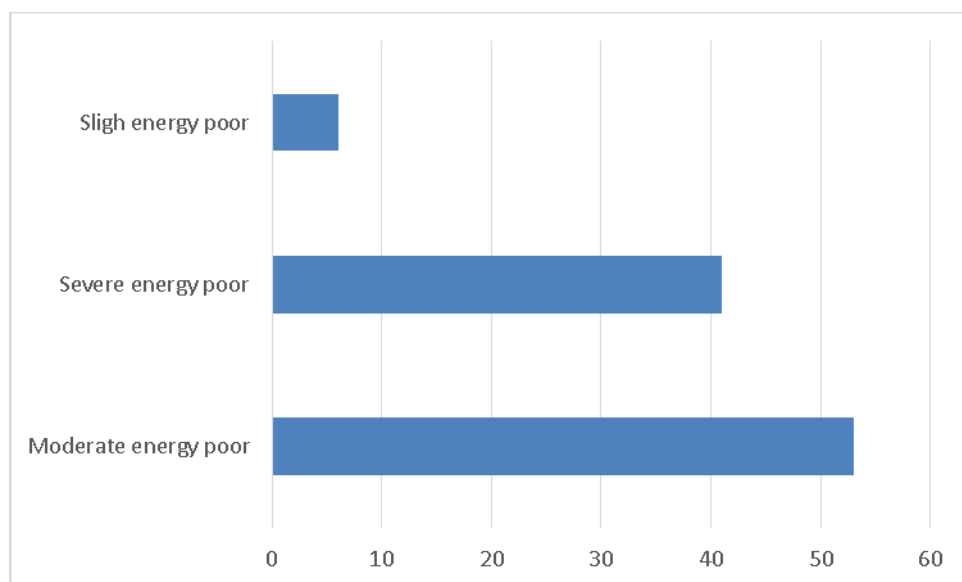
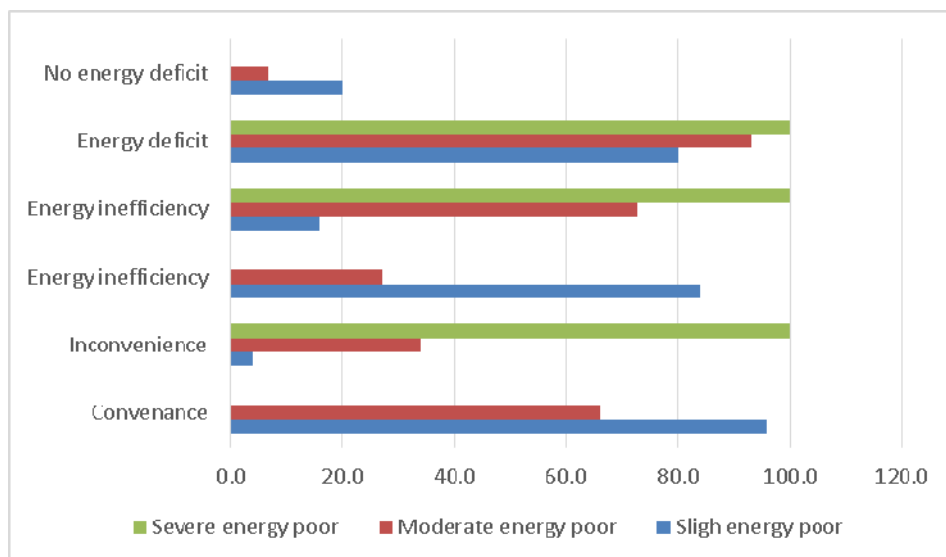
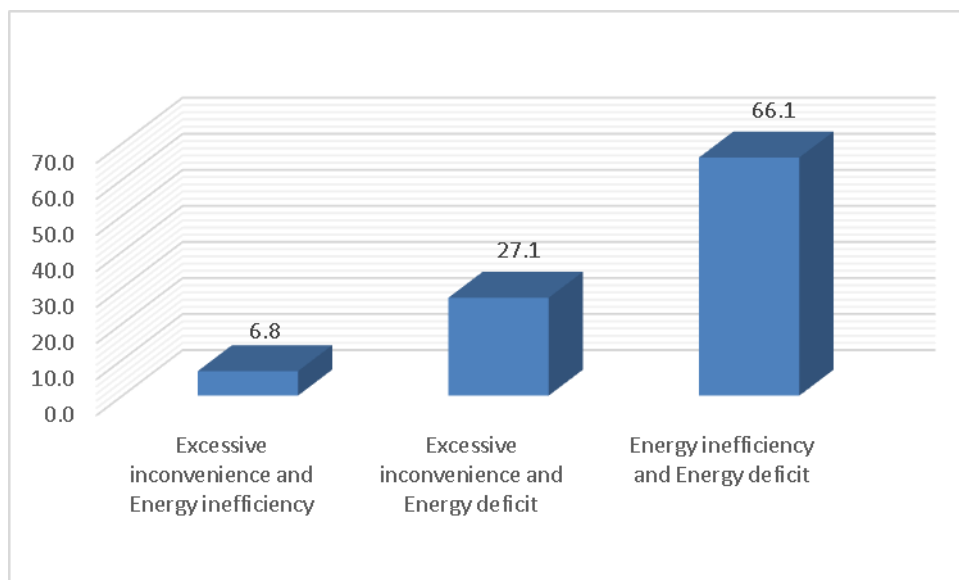
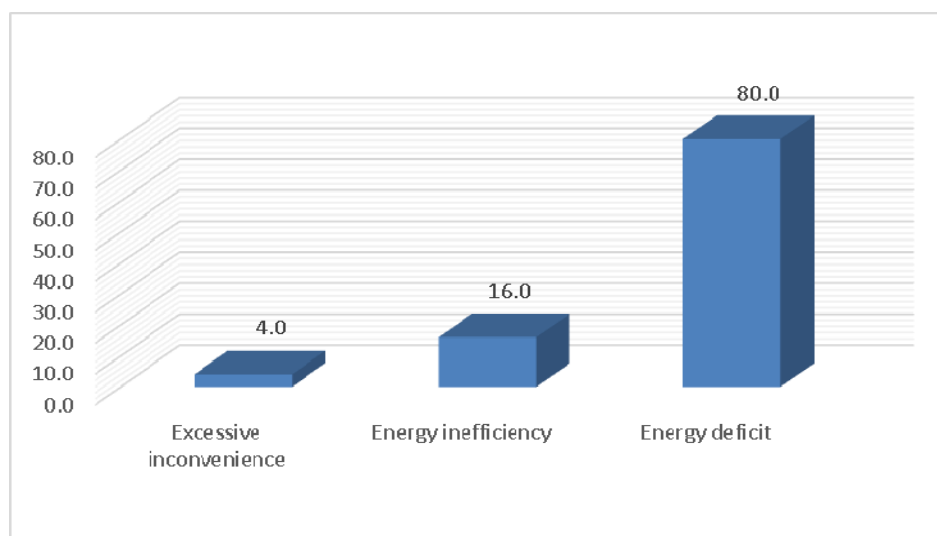


Figure 4 analysis suggests that the main dimension responsible for energy poverty among surveyed households varies depending on sub-group of poor households. Indeed, households in severe fuel poverty have unfavourable scores for all three dimensions. On the other hand, moderate energy poor households with unfavourable scores for two dimensions are more affected by energy deficit (93.2%) followed by the use of inefficient equipment (72.9%).

A closer look at Figure 5 shows that among moderate energy-poor households (constituting the large group), the majority (66.1%) present unfavourable scores for both the energy deficit and energy (in) efficiency dimensions. This means that moderately energy-poor households have an insufficient energy to fulfil their energy requirements and are generally dependent on inefficient or poorly functioning equipment. Only 27.1% of moderately energy-poor households showed unfavourable scores for excessive disturbance and energy deficit and only 6.8% showed unfavourable scores for energy inefficiency and excessive disturbance.

Figure 4 Dimensions responsible of energy poverty (see online version for colours)**Figure 5** Households in moderate energy poverty

Slightly energy-poor households results analysis reveals that most of them presented unfavourable energy deficit scores (80%), as illustrated in Figure 6. Energy inefficiency is not largely responsible for their energy poverty situation as only (3.4%) of the slightly poor households presented unfavourable energy (in) efficiency score. As far as excessive disturbance is concerned, it did not appear at all in results for this type of poor households as none of them scored unfavourably on this item.

Figure 6 Moderate energy poor households

Severely energy-poor households, scored unfavourably on all aspects studied. These households therefore lack the lowest energy quantity required for their basic energy needs, supported using low or inefficient equipment. In addition to these two observations, there are also inconveniences or excessive disturbances associated with household's energy mix.

In conclusion, the main causes of surveyed households' energy poverty are energy deficits and inefficient equipment use. To these two main causes are added, to a lesser extent, excessive inconvenience related to households' energy mix. Faced with these various findings, conclusions that emerge are of two kinds. Firstly, household energy deficit (inability to meet basic energy needs), and inefficient equipment use are the main factors responsible for energy poverty among the households surveyed. Secondly, it is understood that excessive inconvenience associated with the household's energy mix is to a lesser extent responsible for households' energy poverty.

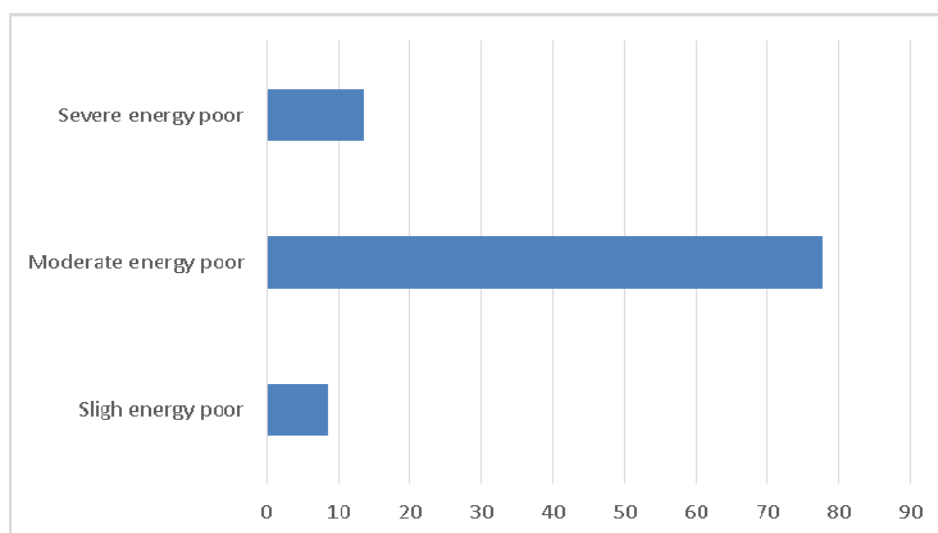
5.1.2 Households' equipment's energy efficiency influence on energy poverty

To study the influence that an improvement in households' equipment energy efficiency would have on energy poverty, simulations are carried out. Indeed, one of the core findings of this study is that inefficient use of equipment is largely responsible, along with the lack of sufficient energy, for households' energy poverty. A simulation is therefore carried out in this respect. Surveyed values of equipment energy efficiency by cooking and lighting energy source are replaced in MOEPI by improved values of equipment energy efficiency for the same energy source. Table 13 summarises these different maximum values used in the modelling by energy source. Results are unprecedented. It can be seen that we have gone from 417 households or about 65.15% of energy poor households to only 212 energy poor households or 33.125% of energy poor households. This represents a 32.025% reduction in energy poor households' number due to household equipment energy efficiency improvement.

Table 13 Maximum energy efficiency values considered

<i>Designation</i>	<i>Efficiency (% for cooking stoves) and lumen/Watt for lamps)</i>
Wood-burning cooking stove	31
Charcoal cooking stove	32
Gas cookers	50
Electric cooker	50
Lamps	80

Figure 7 indicates that most of newly (post-improvement) registered energy-poor households are moderate poor (165 households or 77.8%). Severely energy poor households are 29, or about 13.7%, and the remaining 18 households (8.5%) are in a situation of moderate energy poverty.

Figure 7 Classes of energy poor households post energy efficiency improvements

5.1.3 MOEPI sensitivity analysis

To evaluate MOEPI's strength and reliability, a sensitivity analysis was implemented to assess fluctuations in MOEPI scores as a function of three main parameters that are:

- Total Energy Inconvenience Threshold (TEIT) representing the point at which a household is classified as energy poor due to the substantial inconvenience linked to its energy consumption.
- TER which is a threshold value in kWh under which, a household lacks sufficient energy and falls into energy poor category.
- Total Energy Efficiency Threshold (TEFT), under which a household is classified as energy inefficient for equipment poor energy efficiency.

These three variables considered for sensitivity analysis represent threshold values for each of three energy poverty dimensions: energy discomfort, energy deficit and energy efficiency. Threshold values for each of three dimensions are those that could influence the MOEPI results.

Sensitivity analysis consisted of keeping two threshold values fixed while varying the third by plus or minus 5%, 10%, 15% and 20% of its initial average value. This methodology allowed us to study MOEPI sensitivity to variations in each of these threshold values as shown in Figures 8, 9 and 10.

Figure 8 MOEPI variation as a function of TEIT

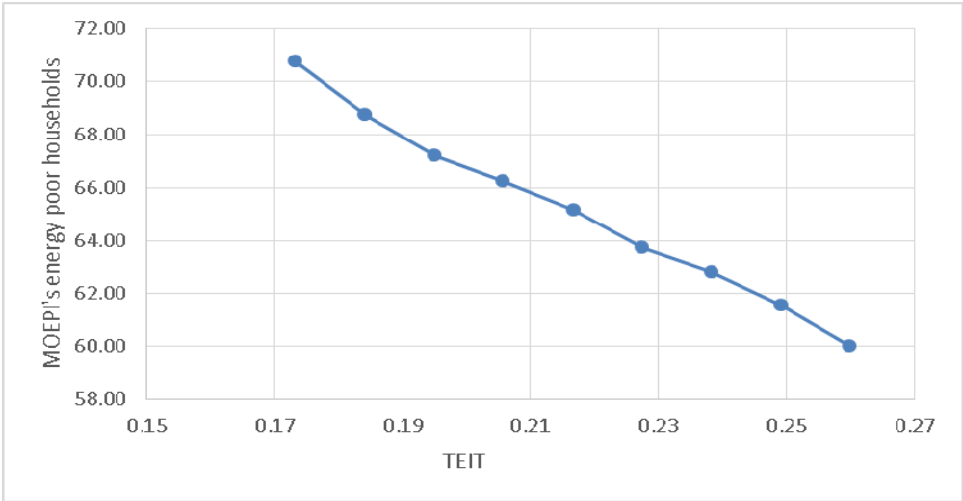


Figure 9 MOEPI variation as a function of TER

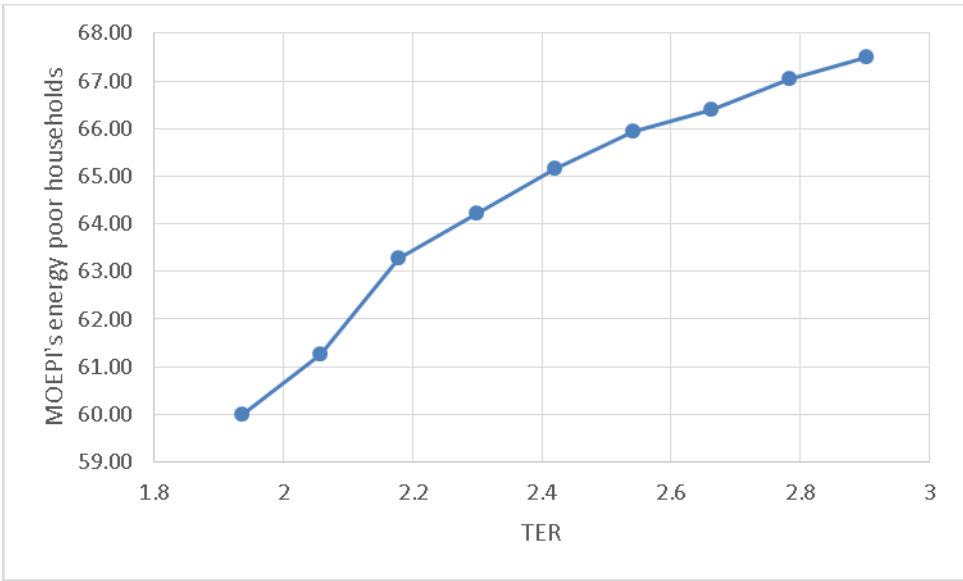


Figure 10 MOEPI variation as a function of TEFT

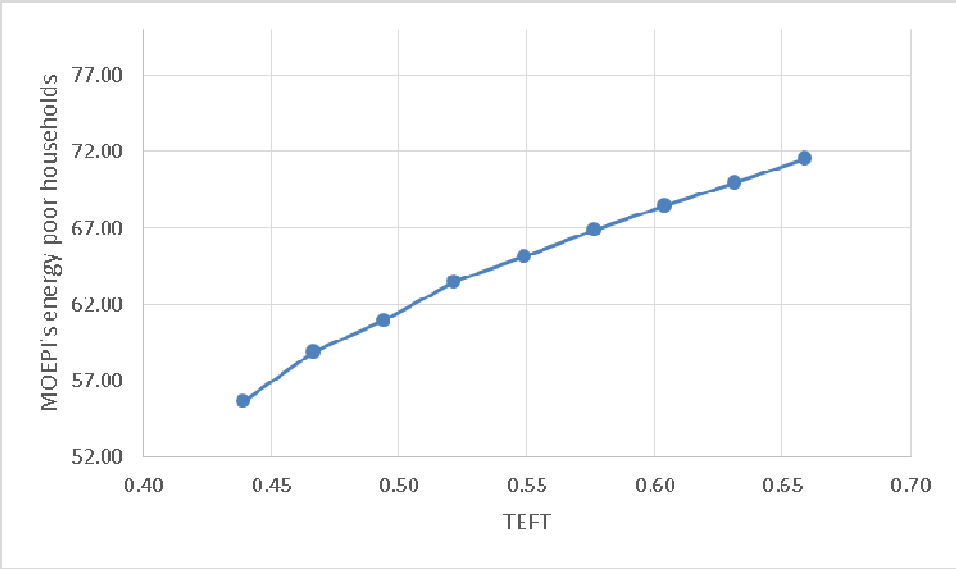


Figure 8 shows household energy poverty rate revealed by MOEPI decreases as energy discomfort threshold increases. Figures 9 and 10 show that the MOEPI poverty rate increases with energy deficit threshold and with energy efficiency threshold. MOEPI as explained above is obtained by taking simple arithmetic average of three scores representing each of energy poverty dimensions. Thus, results of sensitivity analysis can be explained. Indeed, if energy inconvenience threshold is increased, this leads to a decrease in the considered household energy inconvenience score (EIE). The other two threshold values being kept constant, we note a decrease in the MOEPI score, leading household into more severe energy poverty if the household was energy poor or leading the household into energy vulnerability even if it is not energy poor. In Figures 9 and 10, there is an energy poor household's number increase. Energy efficiency threshold increase exposes households using inefficient energy technologies to a decrease in their score for energy efficiency dimension (EEG). Thus, MOEPI will decrease for the household in question, increasing energy poor households' proportion of (see Figure 10). The same remark is made for energy deficit (ES) dimension (see Figure 9).

5.2 Discussion

5.2.1 Comparison of EPI and MOEPI

EPI implementation on surveyed households reveals that 461 of them or about 72% of the surveyed households are energy poor while, as mentioned earlier, MOEPI reveals 65.15% of energy poor households (see Table 14). According to EPI, 56.18% of energy poor households are in a situation of excessive inconvenience compared to 59.13% with MOEPI. The excessive inconvenience dimension in MOEPI is more responsible for household energy poverty than in EPI. Indeed, MOEPI integrates 03 new indicators of energy inconvenience in addition to 07 used in the PPE. Thus, energy inconvenience is

more noticeable and marked in MOEPI than in EPI. Considering drop-out rate or decrease in school performance, exposure time to biomass and fossil fuels and energy cost has improved energy inconvenience dimension assessment, thus making the MOEPI more robust.

Table 14 Comparison EPI-MOEPI

<i>Designation</i>	<i>MOEPI</i>	<i>EPI</i>	<i>Gap</i>
Energy poor households	417	461	9.55%
Poor households with excessive inconvenience	247	259	4.63%
Poor households with inefficient equipment	336	–	–

5.2.2 Comparative study with other approaches to measuring fuel poverty

MOEPI's methodology defines energy poverty as conjunction of three dimensions: energy deficit, energy inconvenience and equipment energy efficiency. This approach is opposed to approaches that measure energy access or modern energy deprivation as is the case with the MEPI (Nussbaumer et al., 2012). MEPI's implementation on the same household's sample indicates a score of 0.48 (see Table 15). MEPI shows fewer energy poor households than the MOEPI. This result makes it clear that both of two indices do not measure the same thing. This result would be difficult to compare with MOEPI because the two indexes are based on different methodological approaches and therefore do not measure the same thing. MEPI proposed by Nussbaumer et al. (2012) measured access on criteria such as entertainment (radio, television, computer), space heating or cooling or functions performed by household appliances such as a refrigerator, washing machine and electric geyser, unlike MOEPI which is based on 3D. MOEPI capture better more energy poverty in sub-Saharan countries, where access to energy is a daily challenge. Obviously, refrigerator, radio, television, etc., are useful for households but are not essential for households in sub-Saharan Africa where alternatives exist for food storing and entertainment. Entertainment is not conditioned by possession of a radio or a television, each people of world and each civilisation has in its culture various ways of distraction or amusement. Africans, especially in rural areas, have many entertaining traditions and practices. Using then the possession of a radio, refrigerator or television cannot mean that a household or person is energy poor or not. Households may not have access to electricity or a television or a microwave and still feel comfortable or energy-efficient in their environment. The same is true of the use of the appliance criterion to measure access to energy. Owning a refrigerator is not essential for a household. One can do without preserving foodstuffs. Yes, these criteria can be used to assess access to electricity or modern energy in a broader sense, but they are not appropriate for assessing energy poverty because defining energy poverty as not having access to modern energy sources is questionable. Energy poverty encompasses multiple dimensions and should be addressed according to the specificities of each environment. Better still, in sub-Saharan Africa, not being able to cool or heat one's home is not a relevant criterion for assessing household energy poverty. The climate in this region does not expose people to extreme cold or hot conditions that force them to heat or cool their homes. In other words, not cooling one's room during the dry season, even in Sahelian countries, does not systematically lead to the death of the population, and the same is true for heating, which is unnecessary even in the harmattan period. As a result, it is not relevant to consider the

heating or cooling of houses when assessing the minimum household energy requirement to meet its basic needs in sub-Saharan Africa.

Table 15 MEPI results on the same sample of households

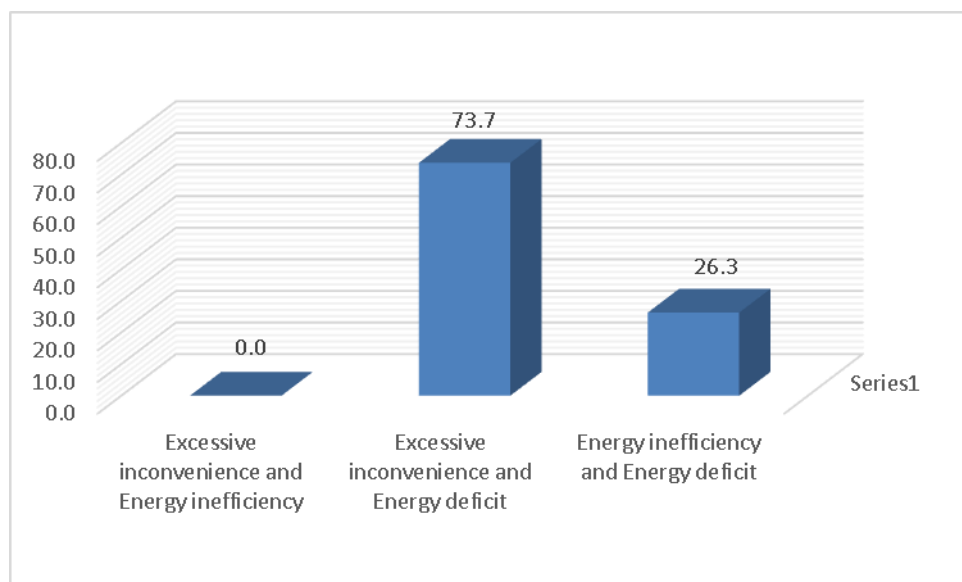
<i>q</i>	<i>H</i>	<i>A</i>	<i>MEPI</i>
478	0.75	0.64	0.48

MOEPI found that 65.15% of the households surveyed were in fuel poverty. A previous study by Fagbemi et al. (2020) on the same sample of households measured house-holds' energy poverty using Boardman economic approach. According to this approach, about 79% of households are in fuel poverty, while with the indicator proposed in this study, we find about 65.15% of poor households. There are fewer poor households with MEPI than with the economic approach. This difference is explained by the relevance and appropriateness of energy poverty measurement tool used. Indeed, several studies have found that economic approach of comparing 10% of household income to house-hold energy expenditure to determine the state of energy poverty is not very appropriate. Indeed, such a measure may be biased in that house-hold's energy expenditure proportion is frequently influenced by factors beyond the type and energy market cost. Efficiency, expenses associated with appliances required for utilising a particular energy source, and most importantly, household size all play crucial roles (Pachauri et al., 2004). Furthermore, a noteworthy portion of the budget may also be attributed to elevated consumption, stemming from either high prices or a substantial household size. This complicates interpretation of this indicator Foster et al. (2000). In addition, proposed tool in this work has advantage of highlighting several aspects in household energy poverty measurement, including equipment energy efficiency, energy deficit or lack of sufficient energy and excessive inconvenience of energy mix. Better still, energy poverty measurement tool is adapted to African context in that it considers culinary and cultural realities of African communities in its assessment, unlike other approaches that do not adapt to African realities. It is one of the first African indicators developed by Africans for the realities of developing countries, and specifically, sub-Saharan Africa.

5.2.3 *Analysis of equipment energy efficiency improvements on energy poverty measurement*

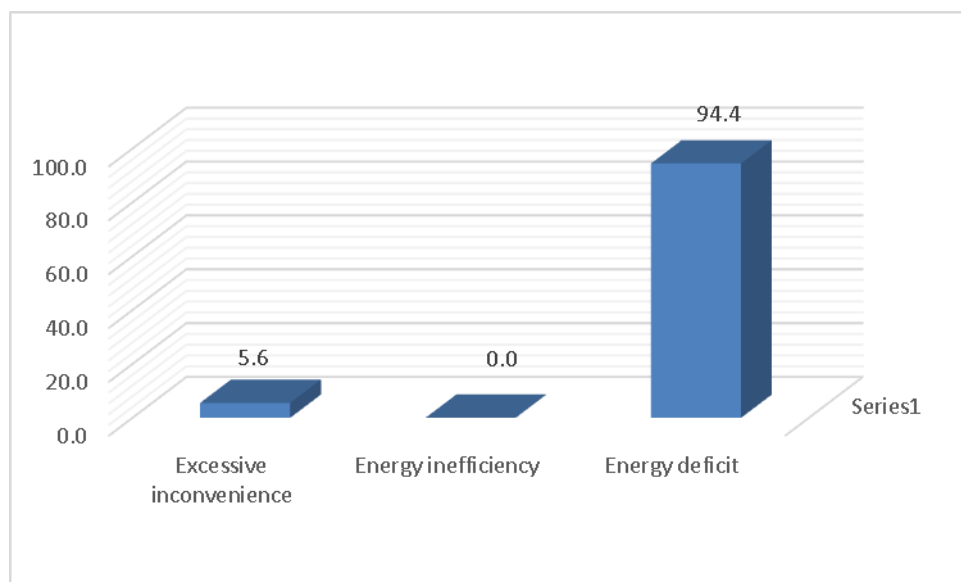
Households revealed as moderately energy poor after simulation, have unfavourable scores for excessive inconvenience and energy deficit (73.7%), and unfavourable scores for energy inefficiency and energy deficit (26.3%) as shown in Figure 11 below. The tandem of excessive inconvenience and energy inefficiency is not at all responsible for fuel poverty in this category. It can be inferred from this that improving equipment energy efficiency can significantly reduce the number of energy poor households. Once the energy efficiency problem is addressed, it becomes clear that the energy deficit and energy inefficiency are the two dimensions responsible for household fuel poverty. The conclusion is that shifting households to more efficient technologies in developing countries will significantly reduce extent and perception of energy poverty. Basically, if, e.g., a household using three-stone stoves for cooking and oil lamps for lighting, now decides to use an improved wood cookstove and an individual solar system using LEDs for lighting, then, that household will no longer be in energy poverty.

Figure 11 Households in moderate energy poverty after improving the energy efficiency of equipment



Slight energy poor households after simulation are mainly in a situation of energy deficit (94.4%) and only a minority (5.6%) are in a situation of excessive disruption (see Figure 12). Energy inefficiency is no longer responsible for household energy poverty. These different results contribute to the same conclusion: an improvement in energy efficiency can reduce the number of poor households considerably. This result has already been addressed in previous studies that demonstrate that an improvement in the energy efficiency of equipment leads to a reduction in household fuel poverty (Boemi and Papadopoulos, 2020; Rosenow et al., 2013). However, this measure alone is not sufficient to effectively combat energy poverty. Ways and means must be found to tackle households' energy poverty issue. How can households be provided with sufficient energy for their energy needs? This question must lead us to find sustainable solutions for households, especially in rural areas. The aim is to provide households with accessible, affordable and affordable energy solutions that will enable them to meet their energy needs.

Our results suggest that an improvement in households' equipment's energy efficiency leads to a decrease in household energy poverty. MOEPI's method is therefore a tool for decision-making tailored for policymakers, for it allows them to know precisely where to act to effectively fight energy poverty.

Figure 12 Households in moderate energy poverty after improving the energy efficiency of equipment

First of all, if those responsible for energy policy in developing countries want to effectively combat energy poverty, they need a measurement tool that can reflect the reality on the ground, i.e., all the main factors determining energy poverty. Implementing the methodology proposed in this paper will enable energy authorities to identify influence that individual energy policies may have on household energy poverty. If, for example, efficient lighting and cooking technologies are popularised and promoted, consequences are numerous and quantifiable with proposed tool. A reduction in household energy poverty is accompanied by a reduction in economic poverty and an improvement in household socio-economic level. Indeed, the use of efficient technologies is very beneficial to household as it reduces energy-related expenses, reduces time and distance spent collecting energy. This allows household to have more income and time to devote to income generating activities as discussed by [53]. These activities will offer some empowerment to women especially in rural areas. Also, improving energy efficiency at household level will help keep children in school and avoid early drop-out due to children's involvement in collecting energy sources. These children will now have the opportunity to spend more time studying and to study properly. Another advantage of the proposed method is that effects on education of not having access to clean and affordable energy are quantifiable and avoidable through well-defined measures to combat energy poverty. The economic (non-pecuniary) benefits are therefore related to education, health and thus to the improvement of the local economy.

Secondly, proposed method allows energy policy makers to clearly identify the best ways to fight energy poverty. Indeed, the study shown that an improvement in household energy efficiency results in a reduction in energy poverty. This result allows us to recommend that policy makers focus on efficient technologies promotion and decentralised energy systems (renewable energy) to effectively combat household energy poverty. For research has shown that enhanced development of renewable energy has the

potential to alleviate energy poverty (Zhao et al., 2022). The promotion of efficient and sustainable technologies should be accompanied by relevant policies to promote clean cooking and renewable energy sources such as biogas, synthetic gas, and biofuels. The implementation of this measure will strongly impact on local economy and the environment. This is because efficient technologies are generally energy efficient, especially charcoal and wood (in developing countries). The aim is to reduce the anthropogenic pressure on the forest cover through efficient technologies. This combined with clean cooking energy promotion will not only improve local economy as explained above but also ensure a healthy and sustainable environment for future generations.

Finally, presented tool is an interesting asset for developing countries where energy realities are generally different from those of developed countries. Suggested approach highlights how energy policies can affect public health and thus the local economy and development. By assessing the link between household members' health, the energy mix used in households and household energy poverty, proposed indicator not only quantifies these links, but also highlights them so that energy policy specialists can take health into account in proposed energy policies.

5.3 Energy justice in the surveyed households

5.3.1 Distributive justice

Surveys data revealed disparities in access to electricity network. Indeed, only 22.69% of households with access to electricity through grid are in the North. In the south, 26.05% of households are electrified and in the centre 51.26%. Further analysis at departmental level shows that Collines' department has the highest number of households with access to electricity through SBEE, with 51.26% of households. Atlantic department has the fewest households connected to the network, with 1.68% of households connected. Alibori and Plateau have the same percentage (6.72%) of households connected to SBEE; Donga has 15.97% and Mono has 17.65%. This suggests that, even within the same region, access to electricity grid is not equitable.

Among surveyed households, 59.22% stated that their localities had not benefited from a rural electrification project in the last five years. On the other hand, 26.25% of them say explained that their localities have benefited from such projects in the last 5 years.

Regions that should benefit from electricity projects identification depends mainly on political leaders and regions to which they belong, or on how favourable or unfavourable the region was to them during elections. For example, a region would be much more favoured to benefit from many rural electrification projects if it is the home region of an influential government member or if it has voted overwhelmingly for government in power. On the other hand, regions hostile to regime are mostly bullied or benefit from bare minimum. However, it must be admitted that electricity grid extension is expensive and therefore State cannot cover all regions at the same time. Choices have to be made. These choices are sometimes based on priority identification of development poles to be connected to the network (MCA-Benin, 2017). Electricity in Benin is therefore a social good but its distribution is not equitable.

5.3.2 Procedural justice

Regarding procedural justice, findings indicate that 388 households (60.63%) state that they have not been consulted in the past by the government to consider their perspectives or energy requirements in a national project or law. Meanwhile, 212 households (33.13%) report having been consulted. The remaining households expressed uncertainty or lack of awareness.

When asked whether household as a citizen believes that they can influence the government's energy policies, responses are mixed (see Table 16). However, most of surveyed households (56.09%) felt that they could influence government's energy policies little or not at all. 32.66% of households responded that they did not know and only 10.63% believed that they could influence government's energy policies to a great extent.

Table 16 Households' views on their involvement in energy policies

	<i>Frequencies</i>	<i>Percentage</i>	<i>Cumulative percentage</i>
Other	4	0.63%	0.63%
A lot	68	10.63%	11.25%
A little	186	29.06%	40.31%
Not at all	173	27.03%	67.34%
Don't know	209	32.66%	100.00%
Total	640	100.00%	100.00%

Revision of SBEE's tariff conditions (lower connection costs and higher costs per kwh of electricity) for the period 2019–2021, follows a public consultation organised by the Electricity Regulatory Authority (ARE) in September 2019. The purpose of this public consultation was to collect the opinions of stakeholders and consumers on document content on tariff revision conditions. Consultation period ran from Thursday 26 September to Friday 4 October 2019. This consultation was carried out online, thus excluding illiterate populations and populations without access to new information and communication technologies. Such a consultation is discriminatory in nature and resulting results would only benefit one segment of the population. The most vulnerable populations were not implicitly involved in this consultation. This evidence suggests that Benin government engages in limited consultation with grassroots population when making energy related decisions.

6 Conclusion

This study introduced a new indicator for energy poverty measurement that incorporates households' technologies energy efficiency. A minimum energy level is determined for energy deficit assessment in this work. Results showed that MOEPI compared to other indicators better fit for developing countries households' energy poverty assessment. The study found that improving households cooking and lighting technologies energy efficiency led to a significant decrease in energy poverty. The index developed in this paper is a decision-making tool in that it identifies the main pillars on which to act to improve energy justice and equity. The flexibility of proposed new indicator allows it to

reflect the energy realities of sub-Saharan countries more accurately and to be used by all. The study also showed that distributive and procedural energy inequities exist and affect people. Energy efficiency policies should therefore be used to combat energy poverty. Policy makers should promote efficient technologies in conjunction with the promotion of clean cooking energy such as biogas, syngas from biomass gasification and biochar. They should also establish a permanent framework for dialogue with the population at the grassroots level in order to truly take their needs into account when making energy-related decisions. The authorities must also consider objective criteria in the choice of localities to benefit from electrification projects to guaranty equity in energy access. The next steps of this study are numerous. But the first one will be to understand how the MOEPI can be used for the particular case of electrical energy in urban areas. The links between energy service quality and households' energy poverty perception in southern Sahara.

Acknowledgements

This study is supported by International Development Research Centre (IDRC) under Project Number [6156]. The project was implemented by Econoler in Benin, Senegal, and Togo in partnership with public universities. The authors would also like to thank Mr. Stephen Junior Zannou-Tchoko who contributed to the sensitivity analysis of the indicator proposed in this article.

References

- Alkire, S. and Foster, J. (2008) *OPHI Working Paper Series Counting and Multidimensional Poverty Measurement, OPHI Working Paper Series*, pp.1–33, 2008.
- Barrella, R., Romero, J.C., Linares, J.I., Arenas, E., Asín, M. and Centeno, E. (2022) 'The dark side of energy poverty: who is underconsuming in Spain and why?', *Energy Social Science Research*, Vol. 86. Doi: 10.1016/j.erss.2021.102428.
- Bersisa, M. (2016) *East Africa collaborative Ph.D. Program in Economics and Management East Africa Research Papers in Economics and Finance Multidimensional Measure of Household Energy Poverty and its Determinants in Ethiopia East Africa Research Papers, East Africa Research Papers in Economics and Finance*, Vol. 15.
- Betto, F., Garengo, P. and Lorenzoni, A. (2020) 'A new measure of Italian hidden energy poverty', *Energy Policy*, Vol. 138. Doi: 10.1016/j.enpol.2019.111237.
- Boardman, B. (1991) *Fuel Poverty: from Cold Homes to Affordable Warmth*, Belhaven Press.
- Boardman, B. (2012) *Fuel Poverty*, Vol. 2, Elsevier Ltd. Doi: 10.1016/B978-0-08-047163-1.00552-X.
- Boemi, S. and Papadopoulos, A.M. (2020) 'Energy & Buildings Energy poverty and energy efficiency improvements: a longitudinal approach of the Hellenic households', *Energy Build*, Vol. 197, pp.242–250. Doi: 10.1016/j.enbuild.2019.05.027.
- Bonatz, N., Guo, R., Wu, W. and Liu, L. (2018) 'A comparative study of the interlinkages between low carbon development and energy poverty in China and Germany by developing an energy poverty index', *Energy Build*. Doi: 10.1016/j.enbuild.2018.09.042.
- Bouzarovski, S. (2017) *Energy Poverty: (Dis) Assembling Europe's Infrastructural Divide*, Springer, Doi: 10.1007/978-3-319-69299-9.
- Che, X., Zhu, B. and Wang, P. (2020) 'Assessing global energy poverty: an integrated approach', *Energy Policy*, Vol. 149. Doi: 10.1016/j.enpol.2020.112099.

- Ekouedjen, E.K., Fagbemi, L.A. and Zannou-tchoko, S.J. (2020) 'Energy performance, safety and durability of charcoal cooking stoves commonly used in West Africa: Benin case study', *AIMS Energy*, Vol. 9, No. 1, pp.68–95. Doi: 10.3934/energy.2021005.
- Fagbemi, L.A., Ekouedjen, E.K., Doubogan, Y.O., Adamon, D.G., Jodoin, L. and Zannou-Tchoko, S.J. (2020) 'Measuring household energy poverty in Benin using Boardman's economic approach', *International Journal of Current Research*, Vol. 12, No. 4, pp.10056–10065. Doi: 10.24941/ijcr.38297.04.2020.
- Foster, V., Tre, J. and Wodon, Q. (2000) *Energy Prices, Energy Efficiency, and Fuel Poverty I Vivien Foster, Jean-Philippe Tre, and Quentin Wodon World Bank*, World Bank.
- Gafa, D.W. and Egbendewe, A.Y.G. (2021) 'Energy poverty in rural West Africa and its determinants: evidence from Senegal and Togo', *Energy Policy*, Vol. 156. Doi: 10.1016/j.enpol.2021.112476.
- Garba, I. and Bellingham, R. (2021) 'Energy poverty: estimating the impact of solid cooking fuels on GDP per capita in developing countries – case of sub-Saharan Africa', *Energy*, Vol. 221. Doi: 10.1016/j.energy.2021.119770.
- Goldemberg, J. (1990) 'One kilowatt per capita', *Bulletin of the Atomic Scientists*, Vol. 46, No. 1, pp.13–14. Doi: 10.1080/00963402.1990.11459775.
- Goldemberg, J., Johansson, T.B., Reddy, K.N.A. and Williams, R. (1985) 'Basic needs and much more with one kilowatt per capita', *Energy in Developing Countries, Royal Swedish Academy of Sciences Basic*, Vol. 14, pp.190–200.
- Gupta, S., Gupta, E. and Sarangi, G.K. (2020) 'Household energy poverty index for India: an analysis of inter-state differences', *Energy Policy*, Vol. 144. Doi: 10.1016/j.enpol.2020.111592.
- Halff, A., Sovacool, B. and Rozhon, J. (2014) *Energy Poverty Global Challenges and Local Solutions*, OXFORD University Press.
- Hosan, S., Rahman, M.M., Karmaker, S.C., Chapman, A.J. and Saha, B.B. (2023) 'Remittances and multidimensional energy poverty: evidence from a household survey in Bangladesh', *Energy*, Vol. 262. Doi: 10.1016/j.energy.2022.125326.
- IAEA (2008) *Indicateurs énergétiques du développement durable: lignes directrices et méthodologies*.
- IEA (2010) *EnErgy povErty How to make modern*.
- INSAE (2018) *Cinquième Enquête Démographique et de Santé au Bénin (EDSB-V)*.
- International Energy Agency (2018) *International Outlook for Energy 2018: a View to 2040*, pp.1–16. Doi: 10.1080/01998595.2012.10491656.
- International Energy Agency (2019) *Africa Energy Outlook 2019 Africa Energy Outlook 2019*.
- Jenkins, K., McCauley, D., Heffron, R., Stephan, H. and Rehner, R. (2016) 'Energy justice: a conceptual review', *Energy Research and Social Science*, Vol. 11, pp.174–182. Doi: 10.1016/j.erss.2015.10.004.
- Johansson, T.B. and Goldemberg, J. (2002) *Energy for Sustainable Development a Policy Agenda*.
- Karmaker, S.C., Sen, K.K., Singha, B., Hosan, S., Chapman, A.J. and Saha, B.B. (2022) 'The mediating effect of energy poverty on child development: empirical evidence from energy poor countries', *Energy*, Vol. 243. Doi: 10.1016/j.energy.2021.123093.
- Khanna, R.A., Li, Y., Mhaisalkar, S., Kumar, M. and Jia, L. (2018) 'Comprehensive energy poverty index: measuring energy poverty and identifying micro-level solutions in South and Southeast Asia', *Energy Policy*, Vol. 132, pp.379–391. Doi: 10.1016/j.enpol.2019.05.034.
- Kumar, A. (2018) 'Energy Research & Social Science Justice and politics in energy access for education, livelihoods and health: how socio-cultural processes mediate the winners and losers', *Energy Research and Social Science*, Vol. 40, pp.3–13. Doi: 10.1016/j.erss.2017.11.029.

- Maxim, A., Apostoae, C., Popescu, C., Istrate, C. and Bostan, I. (2016) 'Implications and measurement of energy poverty across the European Union', *Sustainability*, Vol. 8, No. 483, pp.1–20. Doi: 10.3390/su8050483.
- Mirza, B. and Szirmai, A. (2010) *Towards a New Measurement of Energy Poverty: a Cross-Community Analysis of Rural Pakistan*, United Nations University, Working Paper Series No. 31, pp.1–41.
- Modi, V., McDade, S., Lallement, D. and Saghir, J. (2005) *Energy Services for the Millennium Development Goals*. Report.
- Nations Unies (1990) *Rapport mondial sur le développement humain 1990*.
- Nguyen, C.P. and Su, T.D. (2022) 'The influences of government spending on energy poverty: evidence from developing countries', *Energy*, Vol. 238. Doi: 10.1016/j.energy.2021.121785.
- Nieuwenhout, F., Van de Rijt, P., Wiggelinkhuizen, E. and Van der Plas, R. (2014) 'Rural lighting services, a comparison of lamps for domestic lighting in developing countries', *Netherlands Energy Research Foundation publications*, pp.2–5.
- Nussbaumer, P., Bazilian, M. and Modi, V. (2012) 'Measuring energy poverty: focusing on what matters', *Renewable and Sustainable Energy Reviews*, Vol. 16, No. 1, pp.231–243. Doi: 10.1016/j.rser.2011.07.150.
- Ochieng, C.A., Tonne, C. and Vardoulakis, S. (2013) 'A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya', *Biomass Bioenergy*, Vol. 58, pp.258–266. Doi: 10.1016/j.biombioe.2013.07.017.
- Oum, S. (2018) 'Energy poverty in the Lao PDR and its impacts on education and health', *Energy Policy*, Vol. 132, pp.247–253. Doi: 10.1016/j.enpol.2019.05.030.
- Pachauri, S., Mueller, A., Kemmler, A. and Spreng, D. (2004) 'On measuring energy poverty in Indian households', *World Dev*, Vol. 32, No. 12, pp.2083–2104. Doi: 10.1016/j.worlddev.2004.08.005.
- Practical Action (2014) *Poor people's energy outlook 2014*. pp.1–74. Doi: 10.1017/CBO9781107415324.004.
- Reddy, B.S., Balachandra, P. and Nathan, H.S.K. (2009) 'Universalization of access to modern energy services in Indian households-economic and policy analysis', *Energy Policy*, Vol. 37, No. 11, pp.4645–4657. Doi: 10.1016/j.enpol.2009.06.021.
- Reddy, K.N.A. (1999) 'Goals, strategies and policies for rural energy', *Econ Polit Wkly*, Vol. 34, No. 49, pp.3435–3445.
- REEEP (2009) *50 ways to End Kerosene Lighting*.
- Rosenow, J., Platt, R. and Flanagan, B. (2013) 'Fuel poverty and energy efficiency obligations – a critical assessment of the supplier obligation in the UK', *Energy Policy*, Vol. 62, pp.1194–1203. Doi: 10.1016/j.enpol.2013.07.103.
- Salk, H., Nathan, K. and Hari, L. (2020) 'Towards a new approach in measuring energy poverty: household level analysis of urban India ☆', *Energy Policy*, Vol. 140. Doi: 10.1016/j.enpol.2020.111397.
- SDG 7 (2022) *Iea: tracking SDG 7: the energy progress report* – Google Scholar. Available online at: [https://scholar.google.com/scholar_lookup?title=Tracking SDG 7%3A The Energy Progress Report 2021&author=IEA&publication_year=2021](https://scholar.google.com/scholar_lookup?title=Tracking+SDG+7%3A+The+Energy+Progress+Report+2021&author=IEA&publication_year=2021) (accessed 01 June 2022).
- Siksnylyte-Butkiene, I., Streimikiene, D., Lekavicius, V. and Balezentis, T. (2021) 'Energy poverty indicators: a systematic literature review and comprehensive analysis of integrity', *Sustainable Cities and Society*, Vol. 67. Doi: 10.1016/j.scs.2021.102756.
- Sy, S.A. and Mokaddem, L. (2022) 'Energy poverty in developing countries: a review of the concept and its measurements', *Energy Research and Social Science*, Vol. 89. Doi: 10.1016/j.erss.2022.102562.
- Tombfofa, T.M.K. and Tombfofa, S.S. (2013) 'Multidimensional energy poverty in the south-south geopolitical zone of Nigeria', *Journal of Economics and Sustainable Development*, Vol. 4, No. 20, pp.96–104.

- UN Energy (2005) *The Energy Challenge for Achieving the Millennium Development Goals Energy and the MDGs*.
- Wagner, C.W., Seo, S. and Aelvarsdóttir, A. (2017) ‘Potential Links between Electrification and Education, Policy Brief.
- Walker, G. and Day, R. (2012) ‘Fuel poverty as injustice: integrating distribution, recognition and procedure in the struggle for affordable warmth’, *Energy Policy*, Vol. 49, pp.69–75. Doi: 10.1016/j.enpol.2012.01.044.
- WEO (2017) *International Energy Agency, WEO-2017 Special Report: Energy Access Outlook*.
- WHO (2009) *The Energy Access Situation in Developing Countries*.
- Yadava, R.N. and Sinha, B. (2019) ‘Developing energy access index for measuring energy poverty in forest fringe villages of Madhya Pradesh, India’, *Sustainable Energy Technologies and Assessments*, Vol. 31, pp.167–178. Doi: 10.1016/j.seta.2018.12.013.
- Ye, Y. and Koch, S.F. (2021) ‘Measuring energy poverty in South Africa based on household required energy consumption’, *Energy Economics*, Vol. 103. Doi: 10.1016/j.eneco.2021.105553.
- Zhao, J., Dong, K., Dong, X. and Shahbaz, M. (2022) ‘How renewable energy alleviate energy poverty? A global analysis’, *Renew Energy*, Vol. 186, pp.299–311. Doi: 10.1016/j.renene.2022.01.005.