Ewa Pawliczek

e-mail: ewa.pawliczek@o2.pl

ORCID: 0009-0000-5102-3526

Wroclaw University of Economics and Business

Problems of Measuring Energy Poverty

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Abstract: Energy poverty is a very important social problem, especially in the present economic and geopolitical situation. The aim of the article is to systematize the existing knowledge in the field of measurement and evaluation of this phenomenon, with particular emphasis on multidimensional measures of energy poverty. The author of the study, basing on literature sources, attempts to identify, and classify measures of energy poverty, and characterizes its various dimensions and aspects. As the analyses show, in recent years significant progress has been made in the methodology of measuring this phenomenon, including new approaches that consider the multidimensional measurement of energy poverty.

Keywords: energy poverty, energy poverty indicators, energy poverty measures

1. Introduction

Energy poverty, with a wide variety of definitions, refers to the lack of access to affordable, reliable, and clean energy services that are essential to meet basic needs of people and their well-being. It is a multifaceted problem that affects individuals, households, and entire communities, especially in developing countries (Reddy et al., 2000; Sy & Mokaddem, 2022). It is currently one of the most frequently discussed topics of public and scientific debates in European countries. The wide interest in the subject results from the current geopolitical situation, as well as from the transformation of the energy sector in this area. At the same time, high costs of transformation for households are noted (improvement of the technical standard of buildings, replacement of heat sources), which in turn encourages the development of aid programs in this area. In this context, the fundamental problem is the measurement of energy poverty. This is essential for determining the scope of the problem, identifying the people/households most affected by poverty, and designing effective policies and interventions to address it.

Measuring energy poverty can be particularly crucial in monitoring progress towards sustainable energy access and other development goals, such as poverty reduction or improving health (Nawaz, 2021), as well as identifying the causes and drivers of the problem. These can be low incomes, remote locations, or inadequate infrastructure. This insight should guide future development and mitigation efforts.

Understanding the scale of the problem helps to assess the effectiveness of actions and the impact of policies so far – grants awarded, investments in infrastructure and public awareness campaigns (Primc & Slabe-Erker, 2020). Particularly important in the context of this problem is fairness – energy policy should be accessible to everyone, especially to those most in need. This group includes mainly the elderly, women, and children (Recalde et al., 2019). Constant monitoring of the problem of energy poverty is an opportunity to support cooperation and partnership between governments, international organizations, and private sector entities to solve the problem of energy poverty in a comprehensive and sustainable way.

The main purpose of the article is to systematize the existing knowledge in the field of measurement and evaluation of this phenomenon, with particular emphasis on multidimensional measures of energy poverty. The author uses the method of descriptive research, based on a review of the literature on the subject. The article consists of several parts. After the introduction, the dimensions and scope of the problem of energy poverty were presented, its measures were summarized and each of them was described. Based on the analysis, conclusions were drawn regarding problems related to the measurement of the problem and development opportunities in this area.

2. Dimensions and Scopes of Energy Poverty

The problem of energy poverty is rooted in social and technical factors affecting access to energy. It is based on the availability of energy resources and the energy production and distribution system, and factors such as: income inequality, geographical location, and political instability, which may limit access to modern energy services in many communities. Especially, as emphasized in the introduction, in developing countries (Raghutla & Chittedi, 2022). This problem affects millions of people around the world and has serious social, economic, and environmental consequences. However, energy poverty is not only a lack of access to energy, but also other factors that can affect people's ability to use energy efficiently and effectively. It can have far-reaching consequences for health, education, and economic development. Several dimensions of energy poverty are listed and described below.

2.1. Lack of Access to Modern Energy Services

One of the main dimensions of energy poverty is the lack of access to modern energy services. According to the International Energy Agency (IEA), about 759 million people still have no access to electricity and 2.7 billion people rely on biomass for cooking and heating (González-Eguino, 2015). Lack of access to modern

energy services can have serious consequences for health, education, and economic opportunities. Without electricity, it is difficult to study or work after dark, which affects people's ability to obtain an appropriate level of education and their professional future, the lack of "clean fuels" for cooking exposes residents to air pollution in rooms where meals are prepared, which may cause respiratory diseases and general social exclusion – people affected by energy poverty have a lowered well-being and are more often affected by depression (Thomson et al., 2017).

Cultural and geographical conditions play also an important role in identifying and measuring energy poverty. These factors often differentiate how people use and perceive energy, and whether they have access to energy and what the quality of that access is. Energy consumption patterns can vary greatly by culture and region. In some cultures, it is customary to cook over an open fire or a traditional stove, while in others, modern kitchen appliances such as gas, electric or induction cookers are used. These differences can be very important when measuring, and at the same time can influence energy consumption patterns and types of actions to fight energy poverty (Mahumane & Mulder, 2022).

In rural areas, access to modern energy services may be limited due to the lack of infrastructure, while in urban areas energy poverty may be more related to affordability and access to the electricity grid. In rural areas, the predisposition to use renewable energy sources for individual households is much better, so the balance of electricity or affordability caused by modern energy generation technologies can be considered relatively more often (González-Eguino, 2015; Kaygusuz, 2011).

2.2. Affordability of Energy Services

A dimension of energy poverty is the affordability of energy services. Despite access to electricity, people may not be able to afford it. Many people may reduce their energy consumption or rely on cheaper but more polluting energy sources, with negative consequences for human health and development, as well as for the environment (Amin et al., 2020; Čermáková & Hromada, 2022; Heindl & Schuessler, 2015). Low-income households often cannot afford modern energy services or investments in renewable energy technologies, making energy consumption and its quality less satisfactory, which translates into a growing problem of energy poverty (Abbas et al., 2020; Scarpellini et al., 2019). In some cultures, energy may be seen as a luxury good rather than a necessity, so in such places the energy consumption is assumed to be lower than in places where energy is the order of the day (Amin et al., 2020; Solomon & Calvert, 2017; Sovacool, 2012).

2.3. Efficiency and Productivity of Energy Use

The problem of energy poverty can also be related to the efficiency and productivity in the production and use of energy. The issue of low productivity is important in the case of enterprises (especially in manufacturing), it leads to higher energy consumption, because more energy is needed to produce the same number of products. Improving energy efficiency and productivity can help reduce energy costs and increase access to energy services (Jessel et al., 2019; Karpinska & Śmiech, 2021; Wang et al., 2022). In some regions, traditional house designs can provide natural ventilation and cooling, reducing the need for energy-intensive air conditioning. In other regions, modern buildings can be poorly insulated, leading to high energy consumption for heating and cooling. Often, legal regulations determine certain standards, but this is not implemented in all countries, so measuring energy poverty may not be adequate in the comparison of countries (Castaño-Rosa et al., 2020; Castaño-Rosa et al., 2019).

2.4. Energy Security and Reliability

Another very important dimension of energy poverty is energy security and reliability. For many people, access to energy is unreliable, with frequent power outages. The reason may be improper network connection, lack of maintenance and inspection. This can have serious consequences for businesses and industries that rely on a constant supply of energy, as well as hinder people's daily lives, preventing basic tasks such as cooking, heating, studying, and working. Energy security is an essential component of national security, as countries heavily dependent on imported energy can be vulnerable to supply disruptions and price fluctuations (Del Guayo & Cuesta, 2022; Jessel et al., 2019; Nawaz, 2021).

2.5. Environmental Sustainability

The use of traditional biomass for heating, food preparation, as well as the dependence of access to energy on fossil fuels, can significantly contribute to environmental degradation and climate change. Therefore, it is very important to raise awareness of the risks arising from the use of energy sources derived from non-renewable raw materials or posing a relatively high risk to the natural environment (Biernat-Jarka et al., 2021; Emre & Sozen, 2022). Climate is a key determinant of energy poverty as it affects the demand for heating and cooling services. In countries located in a cold climate zone, the key problem will be heating the place of residence, and in a warm zone, cooling it. In the temperate zone, both household heating and cooling will be considered, depending on the

need in each country. Therefore, a direct comparison of different countries is often unreliable in determining the scale of the energy poverty problem (Streimikiene et al., 2020).

3. Selected Measures of Energy Poverty

The development of anti-poverty programs should be preceded by determining who we consider poor and by analysing the poverty sphere. This is difficult given the diverse determinants of energy poverty, including technical, economic, and cultural factors. In Table 1 selected measures of energy poverty are presented along with the basic characteristics of strengths and weaknesses.

In the measurement of energy poverty, a classic approach can be distinguished, considering income and expenses, and a more complex (multidimensional) approach, where non-economic/non-income factors are also considered. Different approaches are also considered – objective and positive, or these two cognitive perspectives are combined in research. Energy poverty is defined as a situation where a household must spend more than 10% of its income on fuel to maintain satisfactory levels of heating and other energy services. When measuring energy poverty, three main factors are taken into account: energy costs – including the cost of energy for space heating, water heating and cooking, as well as the cost of energy used for lighting and appliances; household income – including any benefits or tax credits they may receive; and energy efficiency – which is measured using the standard assessment procedure (SAP). This assessment considers the building's insulation, the heating system, and the efficiency of lighting and appliances. The 10% indicator is calculated by dividing a household's energy costs by its income and then comparing this indicator to the 10% threshold. If this ratio is greater than 10%, the household is in energy poverty (Boardman, 1991; Castaño-Rosa et al., 2019; Imbert et al., 2016).

Low Income High Cost (LIHC) is a measure used to identify households that experience energy poverty due to low income and high energy costs. An energy poor household in this context is understood as one with low income (Low Income, LI) and relatively high hypothetical energy expenditure (High Cost, HC). Hypothetically high expenses are understood as the sum allowing to meet the needs of the household. It is particularly suitable for low-income households who may not be able to afford basic energy services such as heating, cooling, and lighting. Policies to reduce LIHC tend to focus on increasing the affordability and efficiency of energy services for low-income households through measures such as energy assistance programs, weather programs, and building and equipment energy efficiency standards (Deller et al., 2021; Galvin, 2022; Sareen et al., 2020).

Twice Median National Indicators (2M) is a set of energy poverty indicators based on the concept of energy poverty, defining it as a relative not absolute concept. They assume that a household is in energy poverty if it spends more than

Table 1. Summary of selected measures of energy poverty

Measure	Factors	Approach	Strengths	Limitations
10% indicator	Energy costs, household income, household energy efficiency is considered	Classic, objective	Relatively easy to calculate and considers both energy costs and household income. Considers household energy efficiency, which is an important factor in reducing energy consumption and lowering energy bills	Does not consider the specific needs of vulnerable households, such as households with young children or elderly residents. It is also assumed that households spend a fixed proportion of their income on energy, which may not always be the case
LIHC	A household is classified as energy poor when two criteria are met simultaneously: low income and high hypothetical energy expenditure	Classic, objective	Focuses on low-income households with high energy costs, uses objective data on energy costs and can help policy makers target policy interventions	Is limited in scope, ignores differences in energy consumption patterns and may not capture all sources of energy poverty. It should be used alongside other metrics to gain a more complete understanding of energy poverty
2M indicator	Based on the assumption that a household is in energy poverty if it spends more than twice the national median (2M) household income on energy	Classic, objective	Useful for identifying households that may experience energy poverty compared to the rest of the population, but also for tracking changes in energy poverty over time	May not capture the full extent of energy poverty, especially when the national median income is low and when energy costs are very high
MIS	Aims to measure the minimum level of income that is required for households to achieve a socially acceptable standard of living, based on research and public consultation	Classic, objective	A comprehensive and nuanced way to measure poverty relative to traditional income-based measures. It considers the full range of expenses required for a socially acceptable standard of living	Possibility of bias and limited applicability in different cultural and geographical contexts

AFCP	Based on the concept of „residual income" - amount of income that remains after deducting necessary expenses, including fuel costs	Classic, objective	Considers the fact that energy costs can vary significantly between households and geographical regions. More accurately reflects the real cost of living, especially for low-income households who may spend a disproportionate share of their income on energy	Classify almost all very low-income households as energy poor, regardless of their energy needs
The Multi-Tier Framework	Energy poverty observed in households, manufacturing activities and public places	Multidimensional, subjective	Detailed, covers all sustainability measures	High data intensity, which prevents the indicator from being used in countries and regions where data collection is difficult
(EAI)	Average expenditure on monthly transport, electricity, and cooking fuel	Multidimensional, subjective	Comprehensive, easy to understand, useful for policymaking, updated regularly	Limited scope, date availability, lack of granularity
(MEPI)	Access to energy, its reliability and affordability. Each of the dimensions receives a weight based on the value	Multidimensional, objective and subjective	Multi-dimensional measure, considering many dimensions of energy deprivation, based on a rigorous and transparent methodology. It is also adaptable to different contexts and can be used to inform policy interventions to address energy poverty. Useful tool for researchers and policy makers to assess the extent and severity of energy poverty and to inform policy interventions to address it	Relies on household surveys that may be subject to social desirability bias or recall bias. It may also be affected by cultural and geographic factors that may influence the interpretation of survey questions

Source: own study based on (Castaño-Rosa & Okushima, 2021; Deller et al., 2021; Herrero, 2017; Rademaekers et al., 2016; Romero, Linares, & López, 2018).

twice the national median (2M) household income on energy. The three main 2M indicators are: the energy poverty rate, which measures the percentage of households that are in energy poverty or that spend more than twice the national median household income on energy; the depth of energy poverty, which measures the extent to which households in energy poverty exceed the 2M threshold; and the Fuel Poverty Gap. Energy affordability, representing the difference between the energy costs of households affected by energy poverty and the costs that would be affordable, achievable for them (Antepara et al., 2020; Herrero, 2017; Rademaekers et al., 2016).

The Minimum Income Standard (MIS) considers several factors, including housing costs, food and clothing expenditures, other household items and services, as well as social and cultural participation and transport costs. It is updated annually to reflect changes in prices and living standards of the public. In the context of energy poverty it can be used as an indicator of the income required for households to meet their energy needs, in addition to other basic needs. This can be useful for understanding the scale and extent of energy in the population, as well as the relationship between energy poverty and other dimensions of poverty (Herrero, 2017; Romero et al., 2018; Sareen et al., 2020).

The AFCP index defines energy poverty as a situation in which the household's net income (after deduction of expenses for energy and housing) is lower than 60% of the median net income of all households, with the same deductions. The AFCP is calculated by subtracting estimated energy costs from household income and then comparing the resulting residual income to the poverty threshold. The energy cost estimate is based on household size, housing type and local energy prices. The AFCP can be used to identify households that experience energy poverty as well as general poverty and can help highlight the interaction between energy costs and income in determining poverty levels (Hills, 2011; Legendre & Ricci, 2015).

Energy poverty is not a homogeneous phenomenon, and the use of multidimensional indicators allows us to grasp the depth of this phenomenon more fully. As an example of a multi-dimensional indicator, the Multi-Level Framework combines approaches by using a variety of factors, aggregating and averaging them. Binary measures were used, describing whether the household is connected to electricity, and whether the household cooks on fuels other than solid fuels. The indicator is based on six levels, which can often be presented as biased. The Multi--Level Framework is a tool to measure and set a perspective on energy poverty. They allow for prioritizing investments and monitor progress. In this regard, energy has been singled out as the main enabler of socio-economic development (Bhatia & Angelou, 2015; Siksnelyte-Butkiene et al., 2021).

Another example of a multidimensional indicator is the Energy Access Index (EAI). It consists of three variables, and each of these variables is reflected by several indicators. Transport issues determine the type of fuels used and the type of electricity available, affordability is determined by expenses as a part of income,

safety is related to risk factors and reliability (Siksnelyte-Butkiene et al., 2021; Tait, 2017).

The next multi-dimensional indicator is the Energy Poverty Index (MEPI) which refers to many dimensions of energy deprivation. It is based on the Alkire-Foster multidimensional poverty measurement method which considers the various deprivations experienced by individuals and households across multiple dimensions of well-being. The MEPI covers the following five dimensions of energy poverty:

- cooking fuel – the type of fuel used by households for cooking and whether they have access to clean and safe cooking facilities,
- lighting – the type of lighting used by households and whether they have access to reliable and inexpensive sources of lighting,
- electricity – the level of access to electricity and whether households have reliable and affordable access to electricity for their daily needs,
- heating and cooling – the type of heating and cooling systems used by households and whether they have access to reliable and affordable sources of heating and cooling,
- energy efficiency – the energy efficiency of households and whether they have access to energy-saving devices and technologies.

The MEPI is calculated by weighting the different dimensions of energy poverty and then aggregating the results from the different dimensions to produce a composite energy poverty index. MEPI can be used to compare the extent and severity of energy poverty across countries, regions, and population groups. The use of multidimensional indicators is particularly important in measuring energy poverty, as it makes it easier to show the many aspects of the problem (Nussbaumer et al., 2013; Pelz et al., 2018; Piwowar, 2022; Sadath & Acharya, 2017).

Multidimensional indicators better reflect the real problem and analyse its various aspects. Very often, however, they require much greater financial outlays and analyses to precisely determine the scale of the problem being measured.

4. Summary

While significant progress has been made in identifying and measuring energy poverty, there are still theoretical and practical challenges facing researchers. It is particularly important to focus on the issues listed below.

- Data availability and quality – lack of reliable and up-to-date data on energy access, affordability, and reliability. In many developing countries, data on energy poverty is often incomplete or unavailable, making it difficult to accurately assess the scale of the problem. This increases the need for planning and implementing empirical research.
- Subjectivity and bias – measures are often based on data reported by respondents, which may be subject to perception bias. For example, households

may overestimate or underestimate their energy use, which leads to inaccurate results.
- Lack of standardization – no standard definition or measurement framework, leading to inconsistencies in how energy poverty is scaled across studies and regions. This lack of standardization makes it difficult to compare results and identify best practices.
- Limited in scope – focus on access to electricity and clean fuels for cooking, but do not address other dimensions of energy poverty such as energy security, affordability, and productivity. This can lead to incomplete understanding of the problem and result in ineffective preventive actions.
- Spatial and temporal variability – energy poverty can vary in time and space, making it difficult to accurately capture the scale of the problem. It may be more prevalent in rural than urban areas and may also be more severe at certain times of the year.
- Interactions with other forms of poverty – linked to other forms of poverty, such as income poverty, health poverty and educational poverty. Measuring energy poverty in isolation may not capture the full extent of the problem or its impact on other dimensions of poverty.

The issue of measuring energy poverty results from the overlapping of different impacts of various causes – related to socio-economic, technical, and natural factors. This raises challenges in the development of methods and techniques that consider many different factors, modelling energy needs considering conditions at the local, national, and global level.

Today's civilization progress develops several possibilities related to the use of modern technologies when scaling problems. Data on society is generated continuously through social media posts, emerging content on the Internet, as well as all queries in search engines or intelligent chatbots. The analysis of search data could significantly broaden the knowledge about the real problems of society, especially those that affect people daily, so there is still a huge space for precise, objective, and adequate definition and measurement of energy poverty.

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Problemy pomiaru ubóstwa energetycznego

Streszczenie: Ubóstwo energetyczne jest aktualnym i ważnym problemem społecznym, zwłaszcza w obecnej sytuacji gospodarczej i geopolitycznej. Celem artykułu jest usystematyzowanie istniejącej wiedzy w zakresie pomiaru i oceny tego zjawiska, ze szczególnym uwzględnieniem wielowymiarowych miar ubóstwa energetycznego. Autorka opracowania, opartego literaturze przedmiotu, podejmuje próbę identyfikacji i klasyfikacji miar ubóstwa energetycznego oraz charakteryzuje różne jego wymiary i aspekty. Jak pokazują analizy, w ostatnich latach dokonał się znaczny postęp w metodologii pomiaru tego zjawiska, w tym pojawiły się nowe podejścia uwzględniające wielowymiarowy pomiar ubóstwa energetycznego.

Słowa kluczowe: ubóstwo energetyczne, wskaźniki ubóstwa energetycznego, miary ubóstwa energetycznego