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Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity

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ABSTRACT

This paper provides a systematic review and assessment of the existing (composite) indicators for measuring energy poverty (EP). A total of 71 (composite) indicators have been identified for evaluating EP. The systematic literature review integrates the Search, Appraisal, Synthesis and Analysis (SALSA) framework, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement under PSALSAR (Protocol, Search, Appraisal, Synthesis, Analysis and Report) framework. The framework of Population, Intervention, Comparison, Outcome, and Context (PICOC) is also applied to set the scope of the research. The identified (composite) indicators are assessed based on the Bellagio Sustainability Assessment and Measurement (STAMP) principles. Therefore, recommendations for the practical use of EP indicators are proposed in the article. Structural EP Vulnerability Index, Fuel Poverty Index, and Energy Vulnerability Composite Index are identified as indicators corresponding to the Bellagio STAMP principles to the highest possible extent.

1. Introduction

The concept of energy poverty (EP) is analysed based on two dimensions: (i) absence of physical opportunity to connect/acquire energy, and/or (ii) inability to consume modern energy for various reasons. Studies on EP are relevant to both developed and developing countries (Ayodele, Ogunjuyigbe, & Opebiyi, 2018; Dagoumas & Kitsios, 2014). In the context of developed countries, definitions for energy justice, energy vulnerability, and fuel poverty are often found in the literature. In many developing countries, universal access to energy resources is still a challenge. In developing countries, electricity may not be easily available for majority of population which leads to dependence on solid fuels that not only pollute the environment but are also hazardous to health. Moreover, people may not have adequate financial resources and this perhaps impedes access to modern energy sources (Charlier & Kahouli, 2019). In 2018, only 89.5 percent of the world population had access to electricity, an only 60 percent in Africa. In 28 countries worldwide, less than 50 percent of the population has access to electricity (World Bank, 2020). Thus, when studies on developing countries deal with energy poverty, only the aspect concerning access to energy sources is often analysed. Therefore, the duality of the concept of energy poverty in terms of limited access to modern energy services and energy expenditure poverty engenders many problems for creating valid indicator systems and indices to measure energy poverty.

In both scientific literature and strategic documents, EP is a topical issue and does not follow a single definition. All EP definitions can be summarised into two main categories: (i) very high share of income spent on energy needs, and (ii) inability to consume modern energy for various reasons (Streimikiene, Lekavicius, Baležentis, Kyriakopoulos, & Abrhám, 2020). Some authors try to identify a boundary between EP and fuel poverty and delineate these terms. According to Li, Lloyd, Liang, and Wei (2014), EP is manifested by the lack of modern energy and poor infrastructure (e.g. absence of the power networks) that are most acute in developing countries. Fuel poverty indicates the ability to buy the required amount of energy and relates to income. Only cursory attempts to draw this boundary between the terms can be found. Some authors also use the term ‘energy justice’, which includes the following four fundamental rights or needs: right to healthy and sustainably produced energy, right to quality energy infrastructure, right to availability of energy, and right to secure uninterrupted supply of energy services (Hernandez, 2015). Consequently, energy justice is the supply of secure, affordable, and sustainable energy for everyone (Fortier, Teron, Reames,

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Munardy, & Sullivan, 2019). Since there is no boundary between these terms, and the concepts are all similar, we embark on the literature analysis that includes all three terms in the search, and takes into account possible interpretations of EP and its measures.

The United Nations (UN) (2000) proposed a modern concept of EP and describes it as inability to obtain materially necessary level of high quality and reliable energy that is affordable, safe, and environmentally friendly. This concept shows a clear link between access to energy and environmental impact. Therefore, this concept can be considered universal and suitable for solving the current energy problems. Often, in defining and measuring EP, the focus shifts to the economic aspects, and economic indicators are selected as the key measures. However, attention should be paid to not only the economic aspects but also social and environmental elements, and EP measurement systems must include all three dimensions. Only then will an EP indicator reflect the most topical concerns. Note that energy consumption and production also needs to adhere to the principles of sustainability (Ibrahiem & Hanafy, 2020; Iqbal, Chu, & Hali, 2019; Yan, Qin, Zhang, Li, & Chen, 2020).

EP is analysed across various dimensions: some studies focus on the impact of EP on social factors and health (Day, Walker, & Simcock, 2016; Gillard, Snell, & Bevan, 2017; Kahouli, 2020; Kose, 2019; Recalde et al., 2019; Thomson, Bouzarovski, & Snell, 2017), while others focus on geographical locations (Robinson et al., 2017; Sanusi & Owoyele, 2016), economic factors (Dagoumas & Kitsios, 2014; Kyprianou & Serghides, 2020; Lin & Wang, 2020; Sokolowski, Lewandowski, Kielczewska, & Bouzarovski, 2020), and political initiatives (Primc & Slabe-Erker, 2020; Uche-Soria & Rodriguez-Monroy, 2020). There are composite energy poverty indicators which include already existing indicators. Therefore, it is important to identify which indicator or composite indicator is appropriate and accurately identifies EP. Essentially, this problem amounts to identifying the 'ideal' (composite) indicator. To address these questions, we present a systematic review of the literature and define the principles for comparing EP indicators.

As there have been multiple instances of the single or composite indicators of the EP, it is necessary to identify the ones that are most suitable for capturing the underlying trends if the EP and delivering evidence-based policy guidelines in the context of sustainable development. The objective of this paper is to compare the EP indicators (whether single or composite ones) in their congruence to the traits of sustainability indicators and, thus, assess their integrity. The following questions are tackled to achieve the objective: (i) what is the scope of the literature review for the EP indicators; (ii) what are the traits of the EP indicators that should be considered in the sense of the sustainability concept; (iii) which EP indicators adhere to the requirements of sustainability measures to the highest extent; and (iv) what are the recommendations for EP measurement based on the principles of sustainability. The framework of Population, Intervention, Comparison, Outcome, and Context (PICOC) (Booth, Sutton, & Papaioannou, 2016) is applied to set the scope of the research. The literature review is based on an integrated Search, Appraisal, Synthesis and Analysis (SALSA) framework, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, & Altman, 2010), and Protocol, Search, Appraisal, Synthesis, Analysis and Report (PSALSAR) framework (Mengista, Soromessab, & Legeseb, 2020a). To assess the indicators and composite indicators in terms of their integrity, the Bellagio Sustainability Assessment and Measurement (STAMP) principles are involved (Pinter, Hardi, Martinuzzi, & Hall, 2012). Based on the Bellagio STAMP, we develop criteria for EP indicators.

Section 2 describes the methodology adopted in the systematic literature review. Section 3 presents the analysis and evaluation of indicators and composite indicators of EP. The findings of the systematic literature review are categorised according to the objectives pursued, and the indicators on which the evaluation is based. Section 4 presents a sustainability-oriented framework and recommendations for indicator choice during the assessment of EP.

2. Methodology

The literature search and analysis is based on the SALSA framework. This methodology allows for a detailed analysis of the literature by minimising a possible element of subjectivity (Amo, Erkoyuncu, Roy, Palmarini, & Onoufriou, 2018). The SALSA methodology is singled out in the scientific literature as an appropriate tool for identifying, evaluating, and systematising scientific and practical studies (Amo et al., 2018) and guarantees methodological accuracy and completeness of the work (Grant & Booth, 2009). The PRISMA statement also ensures consistency and completeness of the research. The PRISMA statement comprises a checklist of 27 items and a 4-phase flow diagram (identification of papers, screening of papers, eligibility of papers, and papers included) (Moher et al., 2010). Mengista et al. (2020a) merged the SALSA and PRISMA methodologies and integrated PRISMA into the SALSA framework by adding two stages to SALSA, that is, research protocols and reporting results. The new integrated approach proposed by the authors has six main steps abbreviated as PSALSAR (Protocol, Search, Appraisal, Synthesis, Analysis and Report). This approach has been employed in a systematic literature review on the existing knowledge and research gaps in ecosystem services in mountainous regions (Mengista, Soromessab, & Legeseb, 2020b).

An integrated PSALSAR methodology is applied in this work. The systematic literature search and review framework for analysing the indicators and applications for evaluating EP is presented in Table 1.

The research protocol step helps to ensure transparency, repeatability, systematic nature of the literature review, and minimises the element of subjectivity in the research being conducted. At this stage, the essential task is to define the scope of the research. Subsequently, the research questions can be formulated and methods that are most appropriate to achieve the research objective can be selected (Amo et al., 2018; Booth et al., 2016). The PICOC framework is an appropriate tool in determining the scope of research and is used in this research. The framework provides a formal structure that allows for analysing the research questions by their component concepts, thus defining the scope of the research.

In order to address which EP indicators must be used and are appropriate for assessing EP, the following sub-questions must be tackled:

- Which EP indicators are used in the literature?
- What are the methodological preliminaries underlying these indicators?
- Which indicators are most appropriate for EP assessment?

The PICOC framework for this research is presented in Table 2.

The *Search* step consists of creating and executing a search strategy. At the search strategy stage, it is important to make a proper choice of the database so that the literature collected is of high quality and comprises the bulk of documents that are available in the field of science under research.

The phrases used in the search and information found in the publications is searched and refined using the PICOC framework. As another term 'energy justice' is often used with EP, the literature search was performed using the Web of Science (WoS) database with a combination of three topics: 'energy poverty' + 'indicators', 'fuel poverty' + 'indicators,' and 'energy justice' + 'indicators'.

In the *Appraisal* step, the articles obtained during the search are assessed according to the objective of this work. Only publications matching the search criteria are included in the analysis. In selecting publications for analysis, the PRISMA statement recommendations for information search are followed (identifying papers for screening, eligibility, and included papers). The inclusion criteria are as follows: search keywords in the title, abstract, or keywords of article; articles that are published in a scientific peer-reviewed journal, articles published in two categories of the WoS database: Energy and Fuels, Economics. The

Table 1
Systematic literature search and review framework.

Steps	Main tasks and methods
1. Protocol	• Study scope: Indicators and composite indicators for evaluating energy poverty • Method: PICOC framework (Booth et al., 2016)
2. Search	• Search databases on keywords identified
3. Appraisal	• Studies selection • Method: Flow of information through the PRISMA statement (identification, screening, eligibility, and included papers) (Moher et al., 2010) • Snowballing technique (Malinauskaite, Cook, Daviosdottir, Ogmundardottir, & Roman, 2019)
4. Synthesis	• Preparation of template for data extraction • Categorisation of data for further analysis • Method: The PRISMA statement comprising a 27-item checklist (Moher et al., 2010)
5. Analysis	• Analysis of organised data according to selected categories • Comparison of data results • Obtaining conclusions and recommendations
6. Report	• Summarisation of results for public in an article form • Method: The PRISMA statement 27-item checklist (Moher et al., 2010)

Table 2
Justification of research scope based on the PICOC framework.

Concept	Definition	Application
Population	Research studies dealing with EP or energy justice	Scientific articles dealing with indicators, systems, or other methodologies to evaluate energy poverty.
Intervention	Existing approach applied to address the identified question	Identification of indicators and systems used to measure energy poverty.
Comparison	Approaches to contrast the interventions used to measure energy poverty	Difference between the approaches applied to solve the main question.
Outcome	Achievements and gaps of EP measurement in the analysed studies	Existing indicators, systems, and approaches used to assess energy poverty. Limitations related to the development of a methodology and set of indicators
Context	Characteristics of population analysed	Trends, challenges, and gaps in the EP research area; distribution of knowledge and information based on distinguished categories (indicators, methodologies).

exclusion criteria of this review are as follows: review papers, editorial letters, conference proceedings, studies that are not written in English, duplicated studies within the search documents, and studies not categorised as primary research. At this stage, summaries of all the publications selected during the primary search were read and, after the initial review, the content was analysed if the publication conformed to at least one of the inclusion criteria and did not meet any of the exclusion criteria.

In order for the search results to meet the themes of analysis as much as possible, the search for articles was conducted in the WoS database categories of Energy and Fuels, and Economics. Three hundred and twelve articles were found with the search combinations 'energy poverty' + 'indicator', of which 128 met the inclusion criteria; 147 articles were found using the search combination 'fuel poverty' + 'indicator' and 65 publications met the inclusion criteria; 53 articles were found with the search combination 'energy justice' + 'indicator' and 17 publications met the inclusion criteria. From the content analysis, we eliminated proceedings papers (13), non-English language papers (2), and duplicates (more than one search topic) (57). Content analysis covers the period from 1994 to August 2020. The main scientific journals (five or more publications) were Energy Policy (32), Energy and Buildings (9), Energy Economics (8), Energy For Sustainable Development (7), Applied Energy (7), Energies (5), and Energy (5). It is also worth mentioning that 60 percent of the studies were reported in the last three years. This proves the relevance of the topic, the need to seek a universally acceptable concept, and justifies the need to analyse EP indicators and their systems. During content analysis, studies that were not primary research or indirectly related to the research were eliminated (80). In order to find as many EP evaluation indicators and indices as possible, a snowballing technique was applied in this step. While analysing the content of review papers (21) and publications found during the search, those appropriate for analysing this article were also reviewed. Additionally, 23 indices and indicator sets for measuring EP were also found.

Flow of research information according to PRISMA statement is presented in Fig. 1 bellow.

A total of 71 relevant publications were found where different indicator sets and methodologies for EP assessment were presented or applied. Some indicators or indicator sets were applied to different papers, including Multi-dimensional EP index was applied for evaluating a few developing countries (seven different publications).

In the *Synthesis* step, the study data were extracted and classified according to the identified categories as this allows to identify indicators that are used to assess EP. The data extraction categories can be divided into two groups: general and specific. The year of publication, regions/countries of case studies, and type of research can be assigned to the general data. All other data that help to answer the main question of analysis are assigned to the data of specific articles. A checklist of items for information extraction are: year of publication, journal, case study location, application area, aim of study, methodology, and indicators used.

In the *Analysis* step, answers are sought for the key question of analysis, and the classified data are analysed according to the identified criteria. Various sets of indicators are categorised and presented based on their main objective (application area) (Table 3).

It is worth mentioning that the biggest number of indicators and their sets was found in studies that met search criteria 'energy poverty' + 'indicators'. Meanwhile, during the search for 'energy justice', only studies that duplicated with 'energy poverty' have been included for further analysis. Although the concept of 'energy justice' is similar to 'energy poverty' in the scientific literature, research on this topic focuses on renewable technologies and stakeholder assessment; assessments are performed in the non-household sector.

The *Report* stage includes presentation of the essential points of analysis. In presenting the results of the literature review, the PRISMA statement 27-item checklist is followed.

3. Literature review

3.1. Energy Poverty measurement

Some researchers use various combinations of universally accepted EP indicators, while others try to develop new indices which, in their opinion, better reflect the problem under investigation. Yet, another part of the studies was carried out through ad hoc surveys. For example, (Lenz, Munyehirwe, Peters, & Sievert, 2017) investigated factors that

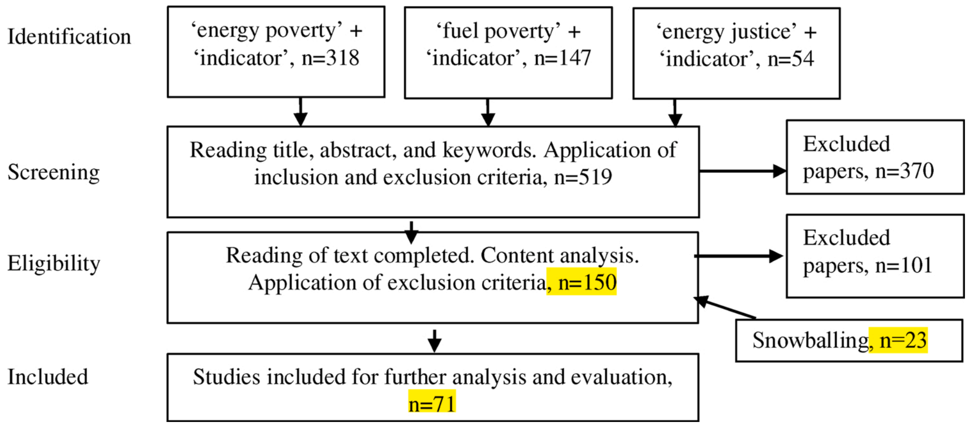

Fig. 1. Flow of research information (according to PRISMA statement).

Table 3
Classification of reviewed studies.

Application areas	Methodology used	Groups of indicators	Location	Year of publication
• Household • Energy policy • Enterprises	• Multi-criteria decision-making tools • Regression analysis • Logistic analysis • Mathematical analysis • Comparative analysis • Construction of indices • LCA • Experts survey • Questionnaire • Multiple linear regression • Artificial neural networks • Scenario construction • Uncertainty and sensitivity analysis	• Efficiency • Income • Habits • Economic • Social • Institutional • Energy prices • Type of energy • Energy consumption • Energy import/ export	• Europe: Greece, Italy, United Kingdom, France, Cyprus, Portugal, Canary Islands, Poland, Spain, Czech Republic, Germany, Ireland, Ukraine, Hungary, Belgium • Asia: China, Philippines, Japan, Thailand, Indonesia, Cambodia, India, Nepal • South America: Mexico, Brazilia, Chile • Africa: Ghana, Nigeria, Kenya, Ecuador • Australia • Multiple countries, European Union (EU), South Africa region, 7 Latin America countries	• 2012 (3) • 2013 (4) • 2014 (3) • 2015 (7) • 2016 (4) • 2017 (4) • 2018 (14) • 2019 (17) • 2020 (15)

are impacted by electrification in South Africa. Although the authors did not use any indexing, the research was carried out through a survey and aimed at determining correlations with variables that are directly related to poverty indicators, such as access to various energy sources and modern appliances, reduction in the use of batteries and kerosene, access to sources of knowledge and information, health effects, and reduction in environmental pollution. Other researchers conducted research on the basis of regression analysis, for example, determining how energy access affects economic development in the region. Aglina, Agbejule, and Nyamuame (2016) used four groups of indicators: health, education, income, and environment (each group of indicators comprises several indicators) to perform regression analysis.

Table 4 presents the systematised results of literature analysis by distinguishing the indices used and the most popular indicators: 10 % indicator; Twice the National Median Indicators (2 M); Minimum Income Standard Indicator (MIS); Low Income High Cost (LIHC); After-Fuel-Cost Poverty Indicator (AFCP); European Union Statistics on Income and Living Conditions (EU-SILC) – Inability to keep the home adequately warm (or cool); EU-SILC – the house has a leaking roof, damp walls/floors/foundations, rot in window frames; EU-SILC – Arrears on utility bills.

According to their essence, the objective indicators are determined by three indicators: income, energy prices, and energy efficiency. In certain instances, these groups can be mutually represented by a single indicator. The indicators vary widely depending on whether developed or developing countries are assessed. In developing countries, the focus is often geared towards energy access, and the studies do not include a broader understanding of EP. However, this type of research cannot be underestimated since it forms the basis of EP and, given the characteristics of a developing country, is usually a telling indicator.

Single indicators provide clear information, they are easy to calculate and apply, and interpret and compare. At the same time, however, the information they provide is quite narrow and usually fails to reflect the full extent of the problem. Therefore, in order to further analyse EP, researchers develop and use various composite indicators and sets of indicators. Some of them are more universal, while others are focused on specific aspects of EP.

3.1.1. Single indicators

The 10 % indicator introduced by Boardman (1991) classifies a household as energy-poor if 10 percent or more income is spent on energy services. The indicator is very pragmatic and easy to calculate. The LIHC indicator proposed by Hills (2012) classifies a household based on the status of EP, that is, when a household's income after energy services expenditure falls below the official poverty threshold and energy expenditure is higher than the median cost of the population. The MIS indicator identifies a household in a situation of EP if its income after energy services expenditure is below the minimum income standard (Moore, 2012). The 2 M indicator includes four similar indicators: double the median, double the mean, double the median share, and double the mean share of household expenditure on energy (Castano-Rosa, Sherriff, Thomson, Guzman, & Marrero, 2019). These indicators classify a household as energy-poor, when a household pays more than double the median, double the mean, double the median

Table 4
Indicators and composite indicators for EP.

Application area	Reference	Issue addressed	Case study location	Indicator used									Index used
				10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	
Household	Lin and Wang (2020)	Energy poverty in China's household sector	China	x			x					x	
Household	Jimenez et al. (2020)	Energy access in Mexico by applying fuzzy logic	Mexico									x	Energy Access Index
Energy policy	Uche-Soria and Rodriguez-Monroy (2020)	Energy poverty in terms of energy planning	Canary Islands	x	x		x	x					
Household	Sokolowski et al. (2020)	Energy poverty in Poland's household sector	Poland		x		x		x	x	x		Multi-dimensional Energy Poverty Index (5 indicators index)
Household	Santillan et al. (2020)	Energy poverty in 7 Latin American countries and correlation with Human Development Index	7 Latin American countries									x	Multi-dimensional Energy Poverty Index (MEPI)
Energy policy	Mazzone (2020)	Link between energy poverty, comfort, and cooling strategies in the Brazilian Amazon	Brazilian Amazon									x	
Energy policy	Primc and Slabe-Erker (2020)	Energy poverty in EU countries and its relations with policy interventions	European Union						x	x	x	x	Energy Poverty Index
Enterprises/ Household	Spiliotis et al. (2020)	Energy poverty in households and utilities	Greece	x								x	A multi-source framework for energy poor households' identification
Household	Betto, Garengo, and Lorenzoni (2020)	Introduction of measures of hidden energy poverty for households	Italy		x							x	Hidden energy poverty indicator
Household	Castano-Rosa et al. (2020)	Presentation of an index for evaluating vulnerability to energy poverty according to monetary, energy, and thermal comfort factors	Salford, UK									x	Index of Vulnerable Homes (IVH)
Household	Churchill, Smyth, and Farrell (2020)	Assessment of the impact of fuel poverty on subjective wellbeing	Australia	x			x					x	
Household	Ahmed and Gasparatos (2020)	Analysis of energy poverty in households around industrial crop projects in Ghana	Ghana									x	Multi-dimensional Energy Poverty Index (MEPI)
Household	Kahouli (2020)	Finding and assessing the relationship between fuel poverty and human health	France	x					x		x		
Household	Kyprianou and Serghides (2020)	Measurement and overview of energy poverty of households in Cyprus.	Cyprus									x	
Household	Castano-Rosa et al. (2019)	Examination of the current level of vulnerability to fuel poverty in a region of England using quantitative data and to provide	England	x			x					x	Index of Vulnerable Homes (IVH)

(*continued on next page*)

Table 4 (*continued*)

Application area	Reference	Issue addressed	Case study location	Indicator used: 10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	Index used
		a tool to assess fuel poverty at a local scale											
Household/ Energy policy	Gouveia et al. (2019)	Designing of a high-resolution index, focusing on heating and cooling in order to identify energy-poor regions and hotspots for local action	Portugal									x	Energy Poverty Vulnerability Index (EPVI)
Household	Mendoza, Cayonte, Leabres, and Manaligod (2019)	Calculating energy poverty of households in the Philippines	Philippines									x	Multi-dimensional Energy Poverty Index (MEPI)
Household / Energy policy	Recalde et al. (2019)	Creation of a structural energy poverty vulnerability (SEPV) index and analysing political and socio-economic conditions in EU countries; and exploring the relationship between index and energy poverty and winter mortality	EU						x			x	Structural Energy Poverty Vulnerability (SEPV) Index
Household	Kose (2019)	Exploring the links between energy poverty and health	–									x	
Household	Okushima (2019)	Evaluation of energy poverty by measuring energy usage in Japan	Japan									x	Multi-dimensional Energy Poverty Index
Household	Aguilar et al. (2019)	Proposal of a new indicator for energy poverty assessment and evaluating energy poverty in the Canary Islands and Spain	Canary Islands and Spain	x			x	x					Compound Energy Poverty Indicator (CEPI)
Household	Sanchez-Guevara et al. (2019)	Exploration of connection between heat exposure due to the Urban Heat Island effect and dwelling characteristics, and heat vulnerability due to age and income	Madrid and London									x	no name
Household/ Energy policy	Charlier and Legendre (2019)	Creation of an index to identify energy-poverty and optimising the policy	France	x			x	x				x	Fuel Poverty Index (FPI)
Household	Ntaintasis, Mirasgedis, and Tourkolias (2019)	Measurement of energy poverty in Greece using several different approaches	Greece	x					x			x	
Household	Boemi and Papadopoulos (2019)	Measurement of energy poverty in Greece.	Greece								x	x	
Household/ Energy policy	Scarpellini, Hernandez, Moneva, Portillo-Tarragona, and Rodriguez (2019)	Measurement of the socio-economic impact of energy poverty in households in Spain considering the different energy policy measures implemented	Spain									x	
Household/ Energy policy	Pysar et al. (2018)	Development of a fuel poverty index in order to determine the	Ukraine	x			x	x				x	Fuel Poverty Index (FPI)

(*continued on next page*)

Table 4 (*continued*)

Application area	Reference	Issue addressed	Case study location	Indicator used									Index used
				10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	
		level of energy security in Ukraine											
Household	Aristondo and Onaindia (2018)	Measurement of the evolution of energy poverty in Spain	Spain						x	x	x		
Household	Burlinson, Giulietti, and Battisti (2018)	Finding the nexus between housing poverty and fuel poverty by applying an alternative modelling strategy of the LIHC indicator	UK				x						
Household	Papada and Kaliampakos (2018)	Evaluation of energy poverty in Greece	Greece	x								x	Stochastic Model of Energy Poverty (SMEP)
Household	Karasek and Pojar (2018)	Analysis of the methods for energy poverty evaluation and comparing the system of support mechanisms for energy poor households in the Czech Republic and the UK	Czech Republic	x								x	no name
Household	Romero et al. (2018)	Comparison of the different methods used to measure energy poverty, and proposing a new methodology to assess energy poverty in Spain	Spain	x		x	x					x	
Household	Belaid (2018)	Assessment of the main aspects affecting fuel poverty in France	France				x					x	
Household	Aristondo and Onaindia (2018)	Assessment of energy poverty in Spain in the period 2004–2015	Spain						x	x	x		
Household	Tait (2017)	Development of a multi-dimensional framework of indicators for assessing household energy access	South Africa	x								x	Energy Access Index
Household	Schlor et al. (2016)	Definition of the societal obstacles in the socio-economic conditions of society by analysing Gordon's trade-off by adapting Thurow's approach	Germany									x	
Household/ Energy policy	Aglina et al. (2016)	Analysis of how improvements in energy access can affect economic development and progress in the region	Economic Community of West African States, Ghana									x	
Household	Heindl and Schuessler (2015)	Emulation of the importance of axioms of aggregated energy poverty measures for affordability measures	–	x	x	x	x					x	
Household	(Heindl, 2015)	Review of fuel poverty concept and approaches for fuel poverty measurement	Germany	x	x	x	x						
Household	Legendre and Ricci (2015)	Application of different measurement approaches for	France	x			x	x					

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Table 4 (*continued*)

Application area	Reference	Issue addressed	Case study location	Indicator used									Index used
				10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	
		fuel poverty evaluation and comparing the results											
Household/ Energy policy	Dagoumas and Kitsios (2014)	Assessment of the effect of the economic crisis on energy poverty in Greece	Greece									x	
Household	Walker et al. (2014)	Development of an indicator for household-level fuel poverty assessment	Northern Ireland	x								x	
Household	Kimemia, Vermaak, Pachauri, and Rhodes (2014)	Evaluation of the relationship between the risk of injuries, household income, and energy poverty	South Africa	x								x	
Energy policy	Chakravarty and Tavoni (2013)	Assessment of the relationship between energy poverty alleviation and climate change mitigation	–									x	
Household	Herrero and Urge-Vorsatz (2012)	Presentation of a new variant of fuel poverty	Hungary									x	
Household	Mattioli et al. (2019)	Testing the previous hypotheses on transport and fuel prices dependency and to provide new evidence	England									x	Composite Vulnerability Indicator
Household	Mattioli et al. (2018)	Proposal of an approach to investigate vulnerability to fuel prices	UK				x					x	Car-related Economic Stress set of indicators
Household	Watson and Maitre (2015)	Analysis of the overlap between fuel poverty and poverty in general	Ireland						x	x	x	x	
Household	Llera-Sastresa et al. (2017)	Presentation of a multi-criteria index for evaluation of different factors that contribute to household energy poverty	Spain	x								x	Energy Vulnerability Composite Index
Household	Pino-Mejías et al. (2018)	Presentation of an index for fuel poverty risk assessment of low-income households when reallocated into social dwellings	Chile									x	Fuel Poverty Potential Risk Index
Household	Fabbri (2015)	Proposal of an index for fuel poverty evaluation correlated to building energy performance	Italy	x								x	Building Fuel Poverty index
Household	Wang et al. (2015)	Construction of an energy poverty comprehensive evaluation index to evaluate regional energy poverty in China	China									x	Comprehensive Energy Poverty Evaluation Index
Household	Marz (2018)	Assessment of the fuel poverty vulnerability of urban neighbourhoods using a spatial multi-criteria decision analysis	Germany									x	Fuel Poverty Index

(*continued on next page*)

Table 4 (*continued*)

Application area	Reference	Issue addressed	Case study location	Indicator used									Index used
				10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	
Household	Bonatz et al. (2019)	Development of an energy poverty index in order to measure energy poverty in China and Germany	China, Germany									x	Energy Poverty Index
Household	Khanna et al. (2019)	Development of a composite energy poverty index in order to measure the extent of EP in the ASEAN region and India	Thailand, Philippines, Indonesia, Cambodia and, India									x	Comprehensive Energy Poverty Index
Enterprises	Ayodele et al. (2018)	Assessment of EP among micro-enterprises in Nigeria	Nigeria									x	Composite Electrical energy Poverty Index
Household/ Energy policy	Olang et al. (2018)	Identification of households without access to modern energy in order to formulate effective policy improvements	Kenya									x	Multi-dimensional Energy Poverty Index
Household	Ntaintasis et al. (2019)	Comparison of different methods (objective, subjective, and composite indicators) for measuring and analysing energy poverty	Greece	x					x			x	
Household	Nussbaumer et al. (2013)	Presentation of advancements of the Multi-dimensional Energy Poverty Index, and evaluating several developing countries	Multiple countries									x	Multi-dimensional Energy Poverty Index
Household	Nussbaumer et al. (2012)	Proposal of a new index to measure EP	–									x	Multi-dimensional Energy Poverty Index
Household	Malla (2013)	Presentation of an index to analyse household energy use and air pollution in Nepal	Nepal									x	Energy Development Index
Household	Okushima (2017)	Presentation of a new approach to measure EP for developed countries	Japan	x								x	Multi-dimensional Energy Poverty Index
Household	Gevelt et al. (2016)	Definition of how socioeconomic characteristics of households lead to EP	India									x	–
Household	Sadath and Acharya (2017)	Preparation of a comprehensive assessment of the extent and various socio-economic implications of EP in India	India									x	Multi-dimensional Energy Poverty Index
Household	Bardaux, Vandeschrick, Moezzi, and Frogneux (2018)	Exploration of the interlinkages between the energy justice and the concept of capabilities	Belgium						x			x	–
Household	Pablo et al. (2019)	Analysis of the situation of EP in Ecuador	Ecuador	x								x	Multidimensional Energy Poverty Index
Household/ Energy policy	Maxim et al. (2016)	Discussions about EP at the EU level and providing an improved EP indicator	EU									x	Compound Energy Poverty Indicator
Household												x	

(*continued on next page*)

Table 4 (*continued*)

Application area	Reference	Issue addressed	Case study location	Indicator used									Index used
				10 %	2 M	MIS	LIHC	AFCP	EU-SILC - Difficulties to keep home adequately warm (or cool)	EU-SILC - The house has a leaking roof, damp walls/floors/ foundations, rot in window frames.	EU-SILC- Inability to pay utility bills on time	Other indicators or questionnaire	
	Gatto and Busato (2020)	Improvement of understanding of vulnerability and proposing an index for energy vulnerability evaluation	Multiple countries										Global Energy Vulnerability Index
Household	Thomson and Snell (2013)	Evaluation of fuel poverty across the EU and identifying factors that increase the risk to slip into fuel poverty	EU						x	x	x	x	
Household	Price, Brazier, and Wang (2012)	Exploring the links between an expenditure based and created subjective measure of fuel poverty assessment and comparing the results	UK	x								x	
Household	Bhatia and Angelou (2015)	Presentation of tool for measuring and tracking progress of energy access of low and middle income countries.	–									x	Multi-Tier Framework
Total				25	5	3	15	5	11	6	8	–	

share, and double the mean share of its income on energy services. The AFCP indicator defines a household as energy-poor, when it does not have enough income to pay for essential energy services, after covering housing and other basic needs (Hills, 2011). The EU-SILC indicators (European Commission, 2014) are self-reported and subjective.

Although these single indicators are used quite widely, they have been recently criticised for lack of empirical justification (Fizaine & Kahouli, 2019) or a too narrow approach towards the problem (Bouzarovski & Herrero, 2017a, 2017b). For instance, the 10 % indicator is criticised for its overly narrow assessment and excessive dependence on energy prices (Legendre & Ricci, 2015; Liddell, Morris, McKenzie, & Rae, 2012; Moore, 2012). The LIHC fails to take into account the increasing energy prices and complicates the monitoring of political interventions (Heindl & Schuessler, 2015; Marz, 2018). The 2 M indicator is criticized for the underlying difficulties in determining the minimum income on an objective basis (Castano-Rosa et al., 2019). The EU-SILC indicators are also denounced for being subjective, dependent on culture, and not universal due to differences in climatic conditions (Bouzarovski, 2014; Castano-Rosa et al., 2019).

The main advantages and disadvantages of the single indicators reported in the literature are provided in Table 5. As one can note, the most often reported advantages of the single EP indicators include their ability to be adapted to the national standards and objective nature. As for the disadvantages, lack of comprehensiveness appears as the most frequent point.

Some authors use slightly adjusted indicators in their studies. For example, Romero, Linares, and Lopez (2018) adjust the LIHC and MIS indicators in their research. Some authors also combine other methods with the indicators. For example, Belaid (2018) calculated LIHC and performed a multi-dimensional statistical analysis and, based on logistic regression, identified factors driving the risk of plunging into fuel poverty. Mattioli, Wadud, and Lucas (2018) proposed a car-related economic stress indicator's set and, based on the LIHC indicator, elasticity estimation and logistic regression identified which group of households spend a large portion of their income on fuel and assessed the extent of their economic stress. Heindl and Schuessler (2015) performed simulation not only with the popular 10 percent, LIHC, MIS, and 2 M indicators but also with a quantile indicator (QI) and relative poverty lines (RPL). Walker, McKenzie, Liddell, and Morris (2014) used a 10 percent indicator. Overall, they used a combination of different parameters to calculate energy consumption: indicators of efficiency of residential heating system, thermal housing characteristics such as the quality of walls, roofing, windows, indoor and outdoor temperature, frequency and habit of heating and ventilation, energy consumption of appliances used, and number inhabitants in the household.

3.1.2. Indicator sets and composite indicators

During the analysis, 41 composite indicators that were developed to measure EP were identified. Since they differ among developing and developed countries, we discuss them based on the following criteria.

Composite indicators applied for developing countries. Nussbaumer, Bazilian, and Modi, 2012; Nussbaumer, Nerini, Onyeji, & Howells, 2013) proposed a Multi-dimensional Energy Poverty Index (MEPI) and evaluated EP in several developing countries. The methodology is based on multi-dimensional poverty measures from the Oxford Poverty and Human Development Initiative (Alkire & Foster, 2009, 2011). Santillan, Cedano, and Martinez (2020) applied the MEPI, proposed by Nussbaumer et al. (2012), to identify EP in seven Latin American countries. Ahmed and Gasparatos (2020) applied this index to analyse and evaluate agricultural projects in Ghana and their impact on household energy poverty. This index comprises of six indicators that focus on energy availability and is appropriate for measuring citizens' access to modern energy (such as electricity or telecommunications) in developing countries. The index certainly does not cover a wider perception of EP. In fact, Olang, Esteban, and Gasparatos (2018) used the same index (MEPI) to identify households without access to modern energy sources in order to formulate effective policy improvements in Kenya. Pablo, Paloma, and Francisco (2019) analysed the position of EP in Ecuador. Similarly, Israel-Akinbo, Snowball, and Fraser (2018) calculated EP in low-income households in South Africa. Sadath and Acharya (2017) used the MEPI adopted by Alkire and Foster (2009) and proposed by Nussbaumer et al. (2012). The index comprises eight dimensions that are grouped into three categories: lighting, cooking, and additional measures. All the categories have equal weight, and all the subcategories are also equal in the category.

Other research studies are also oriented towards aspects of energy access. The Multi-Tier Framework (Bhatia & Angelou, 2015) is an extensive approach that combines energy poverty observed at households, productive activities and public venues. The composite indicator combines multiple indicators and aggregates them by means of averaging. The indicators included in the framework are highly detailed and cover all the dimensions of sustainability. However, this seriously increases data-intensity and precludes the model to be applied in countries and regions where data cannot be easily collected. Culver (2017) identified certain drawbacks of the framework. First, the framework highly relies on the use of the ordinal scale (six tiers) which may render lack of discriminatory power and involves subjective judgments on the thresholds applied. Also, the movement from ordinal scale to the cardinal one is not theoretically sound (e.g., Arrow's impossibility theorem). Second, averaging implies equal importance of the objectives/indicators even though the costs associated with improvement in different indicators may differ considerably (however, this can be taken into account when adjusting the thresholds of tiers). Third,

Table 5
Main advantages and disadvantages of single indicators.

Indicators		10 % indicator	LIHC indicator	MIS indicator	2 M indicator	AFCP indicator	EU-SILC indicators
Advantages	Can be adapted to national standards	x	x	x	x	x	
	Other human needs are considered		x	x		x	
	Energy efficiency of household or technologies used are evaluated (partially)		x				x
	Thermal comfort in the dwelling is evaluated						x
	Characteristics of the dwelling are evaluated						x
	Easy to calculate	x			x		
	Easy to communicate	x					x
	Objective	x	x	x	x	x	
Disadvantages	Particularly sensitive to energy prices	x					
	Unjustified threshold	x					
	Difficulties in fixing the minimum income objectively			x		x	
	Not enough for a full EP measurement	x	x	x	x	x	x
	Indicator is rarely updated						x
	Subjective						x

some indicators are of rather qualitative nature and hard to collect (for instance, absence of past accidents and perception of high electrocution risk). Finally, the Multi-Tier Framework is partially a non-compensatory composite indicator as the lowest tier achieved defines the values of some components of the composite indicator (e.g., household's access to electricity). Seuret-Jimenez, Robles-Bonilla, and Cedano (2020) proposed another index, which is somewhat more limited, for developing countries. The authors applied fuzzy logic to measure the overall Energy Access Index in order to identify and rank regions of Mexico that have least access to energy. The index consists of the following three variables: average expenditure on monthly transport, electricity, and cooking fuel. Four main indicators, namely fuel use, affordability, safety, and reliability, are used in the household Energy Access Index developed by Tait (2017). Several indicators are used to reflect each variable. The fuel use indicator comprises of variables that reflect the type of electricity accessed and fuels consumed, the affordability indicator reflects expenditure as a portion of income, while the safety indicator reflects the number of risk factors identified, and the reliability factor reflects duration of interruptions experienced. While creating the Comprehensive Energy Poverty Index, Khanna, Li, Mhaisalkar, Kumar, and Liang (2019) used four indicators, which are access to electricity, clean fuels, technologies for cooking, total energy supply, and total final energy consumption. This index is intended for developing countries and it measures energy access more than EP. It is obvious that there is clear duality in the concept of 'energy poverty' being linked to developed and developing nations. In developing countries, major energy poverty issues are linked to problems of not having access to modern energy services. In developed countries, energy poverty is more often linked to problems of low income and high energy prices.

Ayodele et al. (2018) analysed EP among micro-enterprises in Nigeria. They calculated the Composite Electrical Energy Poverty Index through the formation of three indices, which are device suitability, electricity affordability, and electricity availability index. Economic indicators, namely income, expenditure, and energy consumption are used to calculate the indices.

Malla (2013) introduced the energy Development Index in order to assess EP in Nepal. The index is constructed as the arithmetic mean of four indicators: commercial energy consumption, electricity consumption in the household sector, share of modern fuels in total household sector energy use, and share of population with access to electricity. Each indicator is calculated using simple formula: (actual value−minimum)/ (maximum value−minimum value). Also, four scenarios with different economic growth and energy systems were considered.

Gevelt, Holzeis, Jones, and Safdar (2016) sought to determine how households' socioeconomic characteristics lead to EP. The authors used four variables (household energy use, willingness-to-pay, disaggregated gross income, and education, health and food security) and regression analysis to assess the impact of EP. The study found statistically significant differences between households with different socio-economic status indicators for expenditure on the variables.

Composite indicators applied for developed countries. Some authors include the previously discussed single indicators in the indices being developed. Sokolowski et al. (2020) present the Multi-dimensional Energy Poverty Index that combines five popular indicators. Two indicators included in the proposed index, specifically 'low income, high costs' and 'high actual costs', are objective indicators, while three indicators, 'not warm enough home' (i.e. inability to keep home adequately warm), 'housing faults', and 'bill difficulties' (i.e. inability to pay bills) are subjective indicators. The proposed index is practically adapted to measuring EP in the Polish household sector. The research considers that a household suffers from EP if this is reflected by the values of at least two indicators. Aguilar, Ramos-Real, and Ramirez-Diaz (2019) use the Compound Energy Poverty Indicator to measure EP in the Canary Islands and Spain. This compound indicator comprises the 10 percent, LIHC, and AFCP indicators. Households are considered 'energy poor' when a household meets the conditions of the LIHC indicator, poor according to the AFCP indicator, and devotes more than 10 percent of its income towards energy. In their study aimed at setting the level of energy security through socially-oriented policies, Pysar, Dergacheva, Bandura, and Pasztorova (2018) proposed another methodology that focuses on the economic aspects of the problem. The authors propose the Fuel Poverty Index which comprises of the following two indicators: monetary poverty and energy inefficiency. Their work reveals the link between energy security and fuel poverty. Castaño-Rosa, Solís-Guzmán, Rubio-Bellido, and Marrero, 2019; Castano-Rosa, Sherriff, Solis-Guzman, & Marrero, 2020) presented the Index for Evaluation of Vulnerability to Energy Poverty, which includes not only economic but also social aspects. The authors use the following four indicators: Monetary Poverty Indicator, Energy Indicator, Comfort Indicator, and Health-Related Quality-Life Cost. In their research, Charlier and Legendre (2019) used the Fuel Poverty Index, which consists of three indicators: standard of living, housing energy inefficiency, and housing temperature. The authors also compared the values of the calculated index with the widely used 10 percent, AFPC, and LIHC indicators. Although the authors argue that the index created by them provides a scale of values that can be compared on the time horizon, rather than simply describing households as poor, this also has the other side, that is, the question arises on the type of household and when it should be considered an 'energy poor household'.

Some studies are oriented towards certain social aspects. Gouveia, Palma, and Simoes (2019) suggest using the energy Poverty Vulnerability Index, consisting of two sub-indices focused on the socio-economic characteristics of the population and energy performance of homes, that is, the population's ability to implement the Alleviation Measures sub-index and the Dwellings' Energy Performance Gap sub-index. Although the proposed index provides a broader approach to calculation, there is still lack of an environmental dimension, which is very important, especially in the context of energy development in developed countries, and includes quality of life indicators. Mattioli, Philips, Anable, and Chatterton (2019) used a composite vulnerability indicator in order to examine how fuel prices lead to EP across different regions of the country and population groups. The LIHC index has data on income, accessibility, vehicle inspection, and vehicle registration. Llera-Sastresa et al. (2017) developed the Energy Vulnerability Composite Index, which is designed to improve the management of social housing. The authors use twenty different indicators, which can be grouped into the following four classes: housing characteristics, characteristics and energy efficiency of appliances, energy costs and habits, and characteristics of householders. The Analytic Hierarchy Process, a multi-criteria decision-making tool was used to assess factors that determine EP in social housing. Pino-Mejías, Perez-Fargallo, Rubio-Bellido, and Pulido-Arcas (2018) developed the Fuel Poverty Potential Risk Index, and by using multiple linear regression and artificial neural networks, sought to calculate the risk of social housing inhabitants entering EP (analysis of the case of Chile is presented). The authors proposed a methodology based on complex mathematical and statistical calculations. Therefore, it is likely that it will not be widely applied in future research as it requires specific knowledge. Schlor, Fischer, and Hake (2016) used the Atkinson index to identify a distributional effect of gross and net income, private consumption, and energy expenditure. The research shows that energy expenditures are equally distributed, and energy can be considered as an indicator of basic household needs irrespective of income. It means that low-income households must spend a higher portion of their income and, as a result, face the bigger risk of experiencing energy poverty. Spiliotis, Arsenopoulos, Kanellou, Psarras, and Kontogiorgos (2020) present a Multi-Source Framework for Energy Poor Households Identification. The framework is based on a 10 percent indicator. It also includes weather indexes as well as some additional economic indicators and is intended for utility companies. Here, neither social nor environmental aspects are considered.

Other indices measure EP and compare countries. For instance, Bonatz, Guo, Wu, and Liu (2019) sought to measure and compare EP at the national level in China and Germany. The index developed by the authors consists of the following two dimensions: access and affordability. Efficiency, income, and energy prices are used to measure the affordability dimension, while clean fuels, electricity, and affordable alternatives are used to measure aspects of access. Experts were consulted to help determine indicator weights. Both dimensions have equal weight in the index. Maxim et al. (2016) proposed the Compound Energy Poverty Indicator for comparing countries, where selected indicators are grouped into two categories: EP indicators and EP pressure factors. The indicator consists of five variables, namely not warm, not cool, dark, arrears, and leaks. Wang, Wang, Li, and Wei (2015) developed the Comprehensive Energy Poverty Evaluation Index to measure EP at the national/regional level. The index consists of 9 indicators and 23 measurements, which can be divided into four groups: energy service availability, energy consumption cleanliness, energy management completeness, and household energy affordability and energy efficiency. Energy service availability indicators are designed to measure access to modern energy; energy consumption cleanliness presents the structure of energy consumed by households; energy management completeness reflects the opportunities for improving energy management in the region, while household energy affordability and energy efficiency reflects household habits and financial opportunities. It should be noted that the following dimensions were included in this index in EP calculations: environmental dimension which manifests itself through measurements such as smoke and dust emissions in waste gas from the residential sector, sulphur dioxide in waste gas from the residential sector, coverage area by solar water heaters in rural areas, percentage of non-solid fuels to commercial energy of household sector, and traditional biomass consumption. Recalde et al. (2019) proposed the Structural Energy Poverty Vulnerability Index to identify EP in each EU country and to determine if there are links to winter mortality. This health-oriented index was prepared with the involvement of experts and can be repeated in research of similar nature. Karasek and Pojar (2018) developed an evaluation system and measured EP at the national level. Five indicators that reflect household energy costs and building and household characteristics were used in the research.

Okushima (2017) presented a multi-dimensional energy poverty index for developed countries with three dimensions of EP: energy costs, income, and energy efficiency of housing. A new Multi-dimensional Energy Poverty Index, which is proposed and used in the study and carried out by Okushima (2019), comprises two indicators: household energy consumption and income. The amount of energy reflects the satisfaction of household needs and revenue reflects affordability. Households are categorised based on socio-demographic characteristics and income. Subsequently, a threshold is set under which the household is classified as suffering from EP. This index considers the characteristics of each household extensively and can be adapted for similar research in other countries or regions. However, it does not cover the environmental aspects of this problem.

Fabbri (2015) presented the Building Fuel Poverty Index based on a building's energy performance. The index includes variables such as household income, energy prices, and building characteristics. Sanchez-Guevara, Peiro, Taylor, Mavrogianni, and Gonzalez (2019) sought to identify EP during the summer in different cities focusing on geographical location, housing characteristics, as well as the household members' age and income. The methodology presents and uses for evaluation indicators such as intensity of Urban Heat Island effect, vulnerability of households (income and age), and households' energy efficiency.

Papada and Kaliampakos (2018) developed the Stochastic Model of Energy Poverty. The model includes indicators such as total heat transfer coefficient, heating degree days, cooling degree days, performance factor of the heating and cooling energy systems and EP ratio, which consists of 12 parameters, and a 10 percent indicator is also used.

Primc and Slabe-Erker (2020) sought to determine the link between EP and political action in the EU. The author developed the Energy Poverty Index with the following three parts: EU-SILC indicators, economic indicators (household income and different types of energy prices) and, in order to find the link with political action, the presence or absence of the country's social or energy policy orientation was also included in the set of measurement indicators. The proposed index is broad enough to cover the problem in question because it is appropriate for both developed and developing countries and includes not only the economic but also the social dimensions.

Marz (2018) developed the Fuel Poverty Index, with three vulnerability dimensions: heating burden, socio-economic, and building vulnerability. The index is constructed based on twelve indicators that represent the economic and social dimensions of sustainability. In this index, the importance of all the dimensions and indicators was evaluated with the help of experts. The authors used reasonable scientific methods in the research. A GIS-MCDA (AHP) approach was used to calculate and compare the data, and sensitivity analysis was used for the expert survey.

The developed and developing countries differ in the extent and depth of the energy poverty. Accordingly, they require using different indicators albeit the same sets could be applied from purely technical perspective. Only one study evaluated together developed and developing countries. Gatto and Busato (2020) proposed a Global Energy Vulnerability Index for national level evaluation with twelve variables. These authors declare that the variables represent four dimensions: societal, economic, environmental, and governance. However, we can identify only two, that is economic and environmental. Such indicators as electricity access, energy intensity, energy imports, renewable energy consumption, energy consumption, fuel export and renewable electricity output are involved in the assessment. However, the issue may be treated differently or whether countries such as Niger, India, South Africa and Norway, Finland, Sweden, Estonia and others may be considered together. For instance, the energy ladder issue is topical for the developed countries, whereas the quality of power supply is also a critical factor in the developing countries.

3.2. Evaluation of EP indicators

In order to assess which indicator or set of indicators is most appropriate for measuring EP, the Bellagio STAMP (Sustainability Assessment and Measurement Principles) can be used (Pinter et al., 2012). Based on these principles, the developed indicator systems were evaluated. The Bellagio STAMP provides the general guidelines based on which it can be assessed if the set of indicators used fully reflects the objectives of sustainable development. The Bellagio STAMP includes eight principles: (1) guiding vision, (2) essential considerations, (3) adequate scope, (4) framework and indicators, (5) transparency, (6) effective communications, (7) broad participation, and (8) continuity and capacity (Pinter et al., 2012). After analysing previous studies that used the Bellagio STAMP principles (Adewumi, Onyango, Moyo, & AlWaer, 2019; Arulnathan, Heidari, Doyon, Li, & Pelletier, 2020; Bartke & Schwarze, 2015), we prepared a four-criteria evaluation system to evaluate indicators for assessing EP (Table 6). Each of criteria has three sub-criteria. Each parameter is evaluated by 1 point if the condition exists. The maximum possible score for the set of indicators is 12.

Based on the developed evaluation system, Table 7 presents the evaluation results. The single indicators, namely 10 percent, 2 M, MIS, LIHC, and AFCP are presented in one group as they are essentially similar. As single indicators, the EU-SILC are presented in a separate group whereas, unlike those mentioned above, they are subjective and differ in their essence. The composite indicators identified during the literature review are evaluated separately.

Several EP measurement indicators and indices confirm that EP is a multi-dimensional problem that may vary in different contexts, and the assessment aspects may also differ. After the evaluation results were summed up, the indices and indicators used were rated between 5 and

Table 6
Evaluation system for indicators sets.

Bellagio STAMP	Connection to Bellagio STAMP principles	Criterion	Sub-criteria	
			Title	Notation
1 - Guiding vision 2 - Essential considerations	• Evaluation is sustainability-orientated	Objectivity	1 Indicators reflecting economic dimensions of the problem are involved	O1
			2 Indicators reflecting social dimensions of the problem are involved	O2
			3 Indicators reflecting environmental dimensions of the problem are involved	O3
4 - Framework and indicators 5 - Transparency	• Methodical justification for selection of indicators • Data sources are clearly indicated	Transparency	4 Methodology for indicator selection is presented	T1
			5 Links to data sources are clearly indicated	T2
			6 Data sources are publicly available	T3
3 - Adequate scope 6 - Effective communications	• Application process is easy to understand • The set of indicators can be easily adapted to other research in the same research category (other location, period)	Practicability and Flexibility	7 A system for indicator calculation is quite simple	PF1
			8 The indicators set can be easily adapted to other research	PF2
			9 The methodology for calculation is presented (or links provided)	PF3
7 - Broad participation 8 - Continuity and capacity	• Stakeholders or experts are involved in selection of indicators and evaluation process	Participation	10 Stakeholders or experts are involved in the process of selection of indicators	P1
			11 Stakeholders or experts are involved in the determination of weights of the indicators	P2
			12 Scientific methods are used for stakeholders or expert participation (selection, concordance of opinions)	P3

Table 7
Evaluation of indicators and indicator systems for EP assessment.

Indicator (set) and reference	Criteria												
	O1	O2	O3	T1	T2	T3	PF1	PF2	PF3	P1	P2	P3	Total
High compliance with the STAMP													
Structural EP Vulnerability Index – Recalde et al. (2019)	x	x		x	x	x	x	x	x	x	x	x	**11**
Marz (2018) - Fuel Poverty Index	x	x		x	x	x	x	x	x	x	x	x	**11**
Energy Vulnerability Composite Index Llera-Sastresa et al. (2017)	x	x		x	x		x	x	x		x	x	9
Medium compliance with the STAMP													
Single indicators - 10 %, 2 M, MIS, LIHC, AFCP	x			x	x	x	x	x	x	x			8
EU-SILC - European Commission (2014)	**x**	**x**			**x**	**x**	**x**	**x**	**x**	x			8
EP index - Primc and Slabe-Erker (2020)	x	x		x	x	x	x	x	x				8
Multi-dimensional EP Index - Okushima (2019)	x	x		x	x	x	x	x	x				8
Indicator - Sanchez-Guevara et al. (2019)	x	x		x	x	x	x	x	x				8
Comprehensive Energy Poverty Evaluation Index Wang et al. (2015)	x	x	x	x	x	x		x	x				8
Energy Poverty Index - Bonatz et al. (2019)	x			x	x	x	x	x	x		x		8
Multi-dimensional Energy Poverty Index - Okushima (2017)	x	x		x	x	x	x	x	x				8
Multi-dimensional EP index (index comprising 5 indicators) - Sokolowski et al. (2020)	x			x	x	x	x	x	x				7
Multi-dimensional EP index - Santillan et al. (2020), Ahmed and Gasparatos (2020), Mendoza et al. (2019), Pablo et al. (2019), Olang et al. (2018), Israel-Akinbo et al. (2018), Nussbaumer et al. (2012, 2013)	x			x	x	x	x	x	x				7
Multi-dimensional EP index – Sadath and Acharya (2017)	x			x	x	x	x	x	x				7
Index of Vulnerable Homes - Castano-Rosa et al. (2020, 2019	x	x		x	x		x	x	x				7
EP Vulnerability Index – Gouveia et al. (2019)	x	x		x	x			x	x		x		7
Compound EP Indicator - Aguilar et al. (2019)	x			x	x	x	x	x	x				7
Indicator-Karasek and Pojar (2018)	x			x	x	x	x	x	x				7
Atkinson Index -. Schlor et al. (2016)	x			x	x	x	x	x	x				7
Composite Vulnerability Indicator – Mattioli et al. (2019)	x	x		x	x	x		x	x				7
Comprehensive Energy Poverty Index - Khanna et al. (2019)	x			x	x	x	x	x	x				7
Energy Development Index - Malla (2013)	x			x	x	x	x	x	x				7
Maxim et al. (2016) - Compound Energy Poverty Indicator	x			x	x	x	x	x	x				7
Global Energy Vulnerability Index - Gatto and Busato (2020)	x		x	x	x	x		x	x				7
Multi-Tier Framework – Bhatia and Angelou (2015)	x	x	x	x	x				x	x			7
Low compliance with the STAMP													
A multi-source framework for identifying energy poor households Spiliotis et al. (2020)	x			x	x		x	x	x				6
Hidden EP indicator -Betto et al. (2020)	x			x	x		x	x	x				6
Fuel Poverty Index - Charlier and Legendre (2019)	x			x	x		x	x	x				6
Fuel Poverty Index (FPI) – Pysar et al. (2018)	x			x		x	x	x	x				6
Energy Access Index – Tait (2017)	x			x	x		x	x	x				6
The Building Fuel Poverty index - Fabbri (2015)	x			x	x	x	x		x				6
Composite Electrical Energy Poverty Index - Ayodele et al. (2018)	x			x	x		x	x	x				6
Stochastic Model of EP - Papada and Kaliampakos (2018)	x			x	x			x	x				5
Energy Access Index - (Seuret-Jimenez et al., 2020)	x				x	x		x	x				5
Fuel Poverty Potential Risk Index - Pino-Mejías et al. (2018)	x	x		x	x				x				5

11 points. It is observed that all the indicators in the developed indices or indicator systems are usually economic. The environmental dimension is included in very few indices developed to measure EP. In several works, the authors (e.g. Castano-Rosa et al., 2020; Castano-Rosa et al., 2019) argue that environmental aspects are also included in the evaluation. However, analysis of the composition of indicators did not identify aspects that could be attributed to environmental aspects.

Most of the evaluation systems developed are simple and can be replicated or adapted for the purpose of conducting research in other countries/regions. However, there are also complex methodologies. The evaluation model proposed by Papada and Kaliampakos (2018) is based on more than one scientific method, and its application is quite complex and requires special knowledge. Experts were invited to participate in the evaluation process for only 5 of the 33 evaluation methodologies. Three of them used scientific methods to organise and justify the participation of experts. The top-rated indices were the Structural EP Vulnerability Index by Recalde et al. (2019) and Fuel Poverty Index by Marz (2018). Both indices do not include environmental aspects in the system of indicators and are based on the use of scientific methods in the selection of indicators and respective weights of those indicators. They can be easily adapted to measure EP in other countries or regions.

4. Sustainability-oriented framework for EP assessment

The process of measuring EP is multi-dimensional and varies depending on time and place, individual characteristics of households (e.g. income, habits, specific energy needs, available technologies), and external conditions (e.g. energy prices, climatic conditions, indicators of the building's energy performance.). The formation of a set of indicators also depends on the level at which the evaluation is carried out – micro or macro. Macro measurement determines the extent and nature of EP. It can identify the main factors underlying the problem and enables to monitor changes in time. However, in most cases, calculations at this level are not suitable for identifying specific households in EP. Therefore, expenditure- and consensual-based approaches are singled out for evaluating EP. The expenditure-based approach is used to examine the relationship between household expenditure and income by setting a threshold. The consensual-based approach is subjective and is used to determine if households pay their bills on time, and if the household inhabitants heat and ventilate the premises sufficiently (Thomson et al., 2017). Both approaches have their limitations and selection of either of the approaches or combining them depends on the objectives of the research (Marz, 2018).

The basic requirements to be considered in developing a reliable and comprehensive set of indicators for measuring EP can be identified. First, it is necessary to ensure that the set of indicators that has been formed fully reflects the modern concept of EP, that is, ensure that it includes not only the economic but also other dimensions of sustainable development. Second, depending on the countries or groups of countries that are being evaluated, the indicators must be selected and adapted considering the characteristics of the country under evaluation. Engaging experts, who can be involved in both the selection and weighting of indicators for developing indices, in the research is a scientifically acceptable way for this purpose. Third, reasonable and reliable methods provide the rationale and accuracy for evaluation.

The selection of representative indicators is necessary to not only measure EP in theory but also to apply the measurement in practice in providing information to policy makers and/or authorities on the current state of EP in the country. A multi-faceted combination of factors are used to determine EP, including physical unavailability of one or another forms of energy, lack of income, energy prices, high costs associated with energy consumption, and the efficiency of housing or technologies used. The planning and implementation of EP mitigation measures requires information on which groups are most affected by EP and which EP factors exist (Pachauri & Spreng, 2011). Moreover, in order to assess the effectiveness of existing policies, it is necessary to determine how this problem changes over time.

Although in terms of energy sustainability, EP is an integral and important part (Kaygusuz, 2012), but the essence of energy sustainability is usually ignored in measuring EP. To address this gap, a set of EP evaluation indicators that fully reflect the modern concept of EP and the objectives of sustainable development, is further developed based on the principles of the Bellagio STAMP. In order to measure EP, as the inability to obtain sufficient quantities of high-quality, reliable, affordable, safe, and environmentally friendly energy, it is necessary to move an essential aspect from the concept of EP itself – the set of indicators or index that is being developed must include economic, social and, environmental aspects. The meso-level approach can also be taken by aggregating the micro-level data up to the desirable level (Gouveia et al., 2019; Okushima, 2019; Sánchez, Fernández, Peiró, & Muñoz, 2020). Table 8 presents the recommended set of EP evaluation indicators.

The likelihood of using renewable energy (renewable fraction) is an indicator that relates directly to EP (Okushima, 2019; Selcuk, Golcek, & Koktas, 2019) which determines energy security (Sovacool & Mukherjee, 2011; Sovacool, 2011)), freedom of choice, a cleaner environment, cleaner air, quality of life in a residential area, and health conditions (Yadoo & Cruickshank, 2012). The development of sustainable energy sources is one of the factors reducing both EP and social poverty, it is helping to achieve energy justice (Chapman, McLellan, & Tezuka, 2018) and is a tool that is designed to achieve long-term results (Terrapon-Pfaff, Dienst, Konig, & Ortiz, 2015).

Presence or absence of political actions/initiatives in the country/region/group where EP is measured must also be included. Policy has a significant impact on the energy efficiency of households and formation of consumption habits. Policy and the market also determine energy prices (therefore, bills to be paid), technologies used, and the possibility to implement them (promotional actions) (Bouzarovski & Herrero, 2017a, 2017b; Kyprianou et al., 2019; Rodriguez-Alvarez, Orea, & Jamasb, 2019; Zhang, Shi, Zhang, & Xiao, 2019). Political measures related to EP can be expressed through revenue, prices, or energy efficiency policies (Mattioli, Lucas, & Marsden, 2017). Income policy occurs when the state applies certain measures that can facilitate a household's ability to pay, obtain the amount of energy it needs (e.g. benefits for people of retirement age, single parents or those raising more children, individuals who receive income that is below the minimum threshold set by the state). A pricing policy is pursued by setting maximum possible energy prices as well as introducing mandatory requirements for energy

Table 8
Set of thematic areas for EP assessment.

Level of assessment	Economic dimension	Social dimension	Environmental dimension
Macro	• Competitive energy prices • Energy consumption • Energy dependence • Energy balances • Policy actions	• Socio-economic and demographic household characteristics • Health • Social policy actions	• Energy efficiency • Renewable Energy • Greenhouse gas emissions • Environmental, energy policy actions
Meso	• Competitive energy prices • Energy expenditure • Presence or absence of political actions/ initiatives	• Socio-economic and demographic characteristics • Health	• Energy efficiency of technologies used • Renewable fraction • Greenhouse gas emissions
Micro	• Energy access • Energy consumption (expenditure) • Energy prices • Income	• Socio-economic and demographic household characteristics • Habits • Health	• Housing characteristics • Energy efficiency of technologies used • Renewable fraction

suppliers to provide discounts to certain groups of individuals. The goal of the energy efficiency policy is associated with climate change mitigation actions. This may include purchase of new, more efficient equipment (Lukanov & Krieger, 2019) and financial incentives for improving the energy performance of a building.

Energy price growth is a significant indicator in measuring EP. Price The global market and government policies influence price volatility. The environmental requirements imposed on energy companies by the state may cause price increases (Preston, White, Thumim, & Bridgeman, 2013). The regulatory actions, meanwhile, impede the ambitions of energy companies to make large profits.

Thermal efficiency and tightness (energy class) of housing and technologies that are energy demand drivers. Therefore, owners of old, unrenovated, large houses are more likely to experience EP.

Household income strongly correlates with EP. Income determines both the opportunity to purchase energy on demand, as well as to renovate housing and introduce new, more efficient energy production technologies. It also affects access to certain benefits, for example, for technology upgrade to home heating, since a part of the costs of the new technology must be borne by the household itself, and even a partial contribution to the costs can be a very heavy burden for the poorest individuals. Fig. 2 presents a schematic representation of the indicator selection process.

Before embarking on the indicator selection process, it is necessary to define the concept of EP and the level at which it will be analysed (micro or macro). It is also important to provide for the tools that will be used. Contribution of experts in the selection of indicators and/or their weights and setting the threshold level is also a significant process in the evaluation. Even the smallest change can lead to significantly different results (Dubois, 2012; Moore, 2012). Since the situation can differ a lot during each evaluation and comprehensive assessment is required, experts can help to develop a more comprehensive set of indicators, and the assigned indicator weights in the final index will be more reasonable as they will be identified not only by one or more authors of the research but by a larger group of professionals in the field. The interfaces of the indicators included must also be considered in the resulting set of indicators, and the correlating indicators must be eliminated. It is also important that a set of indicators is tailored to each region according to its specific characteristics; however, indicators need scaling for applying to different reasons and comparison of them (Robinson, Bouzarovski, & Lindley, 2017). The involvement of experts in the evaluation process is an appropriate approach to be used in this type of research. Quantitative methods are used to aggregate expert opinions and measure their preferences. The use of such methods justifies the participation of experts and provides logical reasoning.

5. Conclusions

Measuring energy poverty (EP) is a complex issue that varies depending on time and place. Overall, it depends on households' individual characteristics (e.g. household income, habits, specific energy needs, available technologies) and external conditions (e.g. energy prices, climatic conditions, indicators of energy performance of the building). Therefore, a variety of EP measurement indicators (whether single or composite) have been created to measure energy poverty. The EP indicators are directly related to the economic domain, whereas social or environmental aspects are considered indirectly (e.g. efficiency-consumption relationship, income, energy consumption). The environmental dimension is included in only a few of the composite indicators developed to measure EP.

Most evaluation systems developed are quite simple and can be easily replicated or adapted for any country or region. However, there are also complex methodologies that require detailed assumptions and are data intensive. The formation of a set of indicators also depends on the level at which the evaluation is carried out – micro or macro. Macro-level analysis can identify the major trends in EP; yet, determinants and mechanisms underlying EP can be revealed by analysing the micro-level data.

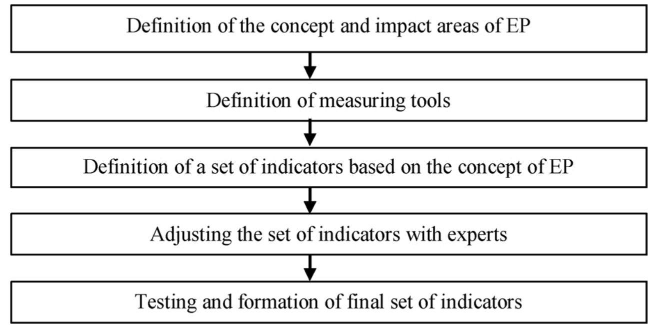

Fig. 2. Indicator selection process.
Source: Prepared according to Rademaekers et al. (2016).

The choice of representative indicators is necessary to provide policy makers with reliable information on the current state of EP in a country.

As EP depends a combination of factors, including physical unavailability of one or another form of energy, lack of income, energy prices, high costs associated with energy consumption, efficiency of housing or technologies used, planning and implementation of EP mitigation measures require information on which groups are most affected; moreover, the type of EP factors that exist for assessing the effectiveness of the existing policies, it is necessary to determine how this problem changes over time. The main policy implication is that before starting the indicator selection process, it is necessary to identify the relevant concepts of EP (including level of aggregation). It is also important to select suitable analytical tools. The choice of experts and their weights are also an important component of evaluation.

The eight principles of the Bellagio STAMP are followed for assessing energy poverty indicator systems and composite indicators. The highest ranking was accorded to composite indicators, which can be considered in EP analysis if data availability is sufficient and the objectives of analysis are addressed by those measures.

The duality of the concept of 'energy poverty' also needs to be solved. It is possible to resolve it to some extent by developing the concepts of 'energy access poverty' and 'energy expenditure poverty'. The concept of 'energy access poverty' is especially useful in the case of developing countries having problems related to accessing modern energy services. The concept of 'energy expenditure poverty' is linked to households in developed countries facing problems related to low incomes and high energy prices.

This study faces limitations in that it covers 71 energy poverty indicators (including composite ones). In order to further analyze the mechanics underlying the composite indicators, a dedicated study is needed. The future research based on the patterns unveiled in this study is necessary by putting main focus on methods for developing energy poverty indicators and addressing strengths and weaknesses of the main measures and approaches used in creating composite energy poverty indicators.

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