Bringing Energy Poverty Research into Local Practice: Exploring Subnational Scale Analyses

Energy Poverty Advisory Hub

February 2022

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Published by the Energy Poverty Advisory Hub

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energy-poverty.ec.europa.eu

February 2022

Design and cover image: Climate Alliance

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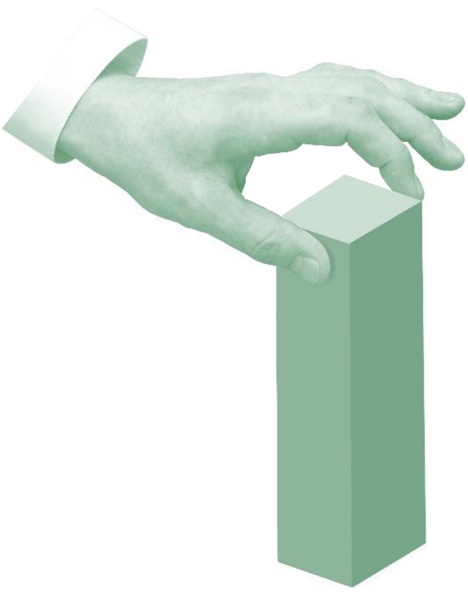

1 Introduction

The European Union (EU) is increasingly targeting energy poverty in its policy action, aiming to boost efforts towards the effective reduction of this issue within a framework of energy efficiency, decarbonisation of the economy, and a clean and just energy transition. The latest effort is “Fit for 55”, aiming to update EU legislation to achieve its climate goals [1]. In the “Clean Energy for All Europeans” legislative package, the EU mandates Member States to address energy poverty in their National Energy and Climate Plans (NECP) and propose measures to mitigate it, if necessary, in each context [2]. The Green Deal also stresses the need to integrate the goal of mitigating energy poverty in wider efforts for a sustainable energy transition [3]. Following this indication, several Member States have developed national strategies to tackle energy poverty, advancing their own definition, methods for measurement and monitoring, and solutions to tackle it in terms of a national point of view. The adequate measuring and monitoring of energy poverty enables a more comprehensive understanding of the breadth and depth of the problem, which is an essential step towards the production of effective evidence-based policy strategies and schemes, as well as the impact assessment of these instruments towards a swifter resolution of the problem [4,5].

However, its causal multidimensionality, the variability of its expression over space and time, and its private nature [6] make measurement a challenging procedure, with experts divided over the best indicators and metrics for measuring energy poverty. This is an ongoing debate at the EU level, as a significant diversity of methods currently exist with different underlying approaches to the problem. Moreover, being a multi-faceted issue, it affects several sectors such as energy, infrastructure, health, and mobility, with a responsibility that can be shifted between departments, creating fragmented and individual responses instead of holistic, integrated, and collaborative policy approaches across all actors.

Most national energy poverty strategies rely primarily on indicators from European Union Statistics on Income and Living Conditions (EU SILC) to more directly evaluate and monitor energy poverty levels in the country. While these indicators have some advantages regarding data collection, monitoring, and commensurability and are generally preferred by the European Union [7,8], they do not constitute a comprehensive approach to the problem and are not explicitly collected for energy poverty evaluation. They do not capture the full extent of the problem, particularly the different facets that make up vulnerability to energy poverty. Furthermore, these indicators are primarily collected at the national level, from a uniform European framework aiming to produce comparable data between Member States, thus not capturing local realities and contexts within countries. Subsequently, they do not enable more nuanced approaches regarding the spatial scale and diversity of determinants.

Researchers support multidimensional composite metrics to capture all the dimensions of energy poverty in one metric [6,9]. Still, these are difficult to transfer to other contexts without undermining transparency and effectiveness. Therefore, selecting indicators is paramount for correctly identifying populations suffering from energy poverty. This process must consider context, scale, and data availability [6].

Energy poverty requires holistic efforts at all levels of governance, from the European to the local level. While national-level evaluations are essential to grasp the dimension of the problem, setting the scene and framing other analyses and measures, regional and local assessments can provide more detailed and insightful perspectives, enabling the unpacking of vulnerability situations that are particular to specific contexts and groups. In this line of thought, ENGAGER [10] advocates for standard methodologies in the European Union, focusing on a regional level. Gouveia *et al.* [11] stress the need for bridging the gap between generic country assessments to case study approaches at the local level. Moreover, under the Just Transition Mechanism [12], the Member States are committed to preparing just territorial transition plans, covering vulnerable regions, by identifying the needs and alleviation measures for these territories to tackle vulnerability, namely to energy poverty.

The identification of households at risk of energy poverty at an early stage can be more accurate and practical at the level of towns, cities, and regions. To monitor the progress of its alleviation, there is a need to connect and align the commitments made at the national level with the energy poverty configurations and population needs at the regional and local levels to monitor progress in energy poverty alleviation. Linking NECPs with the Sustainable Energy and Climate Action Plans (SECAPs) through an indicator framework can be an opportunity to adequately monitor progress. Local authorities play an essential role in detecting energy poverty in their jurisdictions. They may have more detailed data and information on the population, and closer links, together with the social and civil organisations. This more immediate connection enables these authorities to reach the vulnerable population and efficiently provide support. The direct engagement with the local stakeholders and the population, through surveys, interviews, workshops, and co-creation sessions, is crucial in the local diagnosis phase; that is, identifying the energy poor and assessing implementation to increase the effectiveness of measures. Past examples show the implementation of corrective actions, such as providing direct financial support for the payment of energy bills, tax abatements and exemptions, and co-financing energy efficiency measures through loans and grants, similar to national policy efforts. These contribute marginally to improving the lives of affected households, although this benefit is not systematic, as it does eliminate the problem at its roots. Different types of support can be given at the local level, as shown by the rising number and diversity of actions conducted throughout Europe and available in the **Energy Poverty Advisory Hub (EPAH) Atlas**.

Facing energy poverty should be, and is, in fact, a priority for many local authorities. Notwithstanding their ability and resilience to confront complex social, economic, and institutional issues, it still presents complex challenges at different levels, from identifying vulnerable consumers to managing personal situations at the household level. Lack of bottom-up data is an issue that is transversal to all phases of the energy poverty action process, significantly hindering quality impact assessments. Furthermore, the difficulty of developing or selecting adequate metrics to evaluate the problem does not allow for comparing energy poverty levels between locations and Member States and monitoring the impacts of potential implemented measures. With these two issues at play, it becomes a challenge to develop data-driven evidence-based policies, one of the bastions of democratic governance. One of the causes for this situation lies in the disconnection between the research world and policymakers and practitioners (*e.g.,* social services), especially at the local level, which is, in fact, a significant bottleneck that the Energy Poverty Advisory Hub in general, and this report in particular, aim to address. It is essential to strengthen these connections through capacity building for local governments, developing a comprehensive and robust toolkit (*e.g.*, EPAH Atlas, training, and technical support) to improve their ability to face the different energy poverty expressions across the territory. Effective local programmes require the participation of a diverse range of stakeholders, such as local communities, non-governmental organisations, financial institutions, public authorities, and energy companies sharing different responsibilities in a joint effort to tackle this issue [13,14].

Nevertheless, as previously mentioned, energy poverty scholarship in terms of research is diverse. A wide array of methods and case-study analyses have been developed, spanning various contexts and scales, with ongoing debates on the most adequate approaches for identifying consumers affected and/or at risk of energy poverty. All this work has not culminated in a consensus for using one particular method but rather in the agreement that there is a diversity of contexts that require a range of approaches to address them. The assessments conducted up until now form a wide-ranging and diverse group of possibilities, each one providing essential insights for scholarship in energy poverty measures to move forward through finer spatial scales.

Different contexts may require alternative metrics for tailoring policies based on the accurate identification of vulnerable consumers and avoiding the stigmatisation and discrimination of people. Therefore, it is necessary to know the type of data and methods currently available and used across European contexts.

This report conducts a thorough scientific literature review of studies that delve into energy poverty assessment and the identification and targeting of the energy-poor population at subnational spatial scales (smaller than national). When analysing the different studies, we distinguish the terminology used throughout this document between the regional scale (for studies addressing Nomenclature of Territorial Units for Statistics (NUTS) 3), municipalities or equivalent-sized units, and the local scale for smaller territorial units. This report aims to investigate, identify and analyse the variety of data sources, datasets, and methods used in the literature for assessing energy poverty at greater spatial resolution for specific contexts, territories, and populations. Ultimately, the goal is to collect helpful information and knowledge, and channel it in the direction of local governments and organisations to inform their local practice and initiatives. Frequently, local initiatives are supported by local datasets informally collected by local governments and providing a valuable contribution. By tapping into studies in academia, we complement and strengthen both the data resources available to local governments and the toolbox of methods to evaluate this issue and identify the different profiles of vulnerable people.

The report is organised as follows: First, an overview of energy poverty metrology is introduced in Section 2. Subsequently, an analysis and review of regional and local indicators and metrics is conducted in Section 3, aiming to assess their application for specific case studies and available data sources. Section 4 broaches unexplored data and metrics and their link with local organisations and the practical, real-life efforts and initiatives of governments. In Section 5, recommendations for policymaking at the local level are formulated based on the review findings.

2

Energy Poverty Measurement Overview

A selection of appropriate energy poverty indicators for measuring and monitoring is crucial for identifying energy-poor regions and population. It should consider the different causes of the problem, and it is dependent on the availability of resources and data. These two factors vary significantly across the geographical scale. Before focusing on small-scale assessment, it is relevant to study the existing types of indicators in the literature that have been used throughout the years in energy poverty studies and understand the contexts in which they are used. Indicators can be classified according to different aspects, such as objectiveness and subjectiveness, object of measurement (causes, drivers, or outcomes), category, type, outcome, comparability, robustness and quality, and data availability [15].

According to several experts [5,6,15], when considering type, indicators can be divided into **three different approaches**:

Consensual-based, consisting of self-reported experiences and assessments by the occupants regarding thermal comfort or other housing conditions inside their homes, as well as the ability to afford and guarantee the basic energy services.

The most known examples of this kind of energy poverty indicators are the EU-SILC indicators, previously described. The Energy Poverty Observatory, now a part of the Energy Poverty Advisory Hub [16], places them in two different categories – primary and secondary. Primary indicators, such as the “Share of population not able to keep their home adequately warm” and “Share of population having arrears on utility bills” are directly connected to energy poverty. On the other hand, secondary indicators provide information on different aspects of energy poverty but do not directly measure the problem. Examples are the indicator “Share of population with leaks, damp or rot in their dwelling” and the indicator “Average number of rooms per person in rented dwellings”. National surveys also collect self-reported indicators. These indicators can focus on the causes but also on the outcomes of energy poverty.

Expenditure-based, where domestic energy expenditure is compared to income. If expenditure is above a defined threshold of energy poverty, the household is considered energy poor.

This method was first introduced by Boardman [17], who defined as fuel poor the household whose fuel expenditure of all energy services surpassed 10% of the income, a threshold representing at the time twice the median expenditure. Variations of this method have been adopted subsequently in the devolved nations of the United Kingdom [18,19]. The threshold can be based on an absolute or relative measure. In an absolute measure, the threshold is a fixed percentage of the income spent on energy, whereas a relative threshold is based on a median or average energy burden [6]. Relative thresholds vary with fluctuations in energy costs; therefore, becoming a changing target, which can be more challenging to analyse. On the other hand, they can be more accurate in representing energy poverty [6].

The European Commission, through EPAH, proposes two primary expenditure-based relative threshold indicators to evaluate energy poverty: The “Low absolute energy expenditure” (M/2) indicator and the “High share of energy expenditure in income” (2M) indicator [16]. “M/2” is an indicator that captures abnormally low energy expenditure, consisting in the share of households whose absolute energy expenditure is below half the national median. The results of this indicator can have two interpretations: it can be due to the high energy efficiency of the building but also due to the below-average energy consumption of the households. Inversely, the “2M” indicator captures abnormally high energy expenditure. It represents the percentage of households whose energy expenditure share in income is more than twice the national median share.

Another commonly used expenditure-based indicator is the “Low Income High Costs (LIHC)”. This is the indicator officially adopted in England to measure energy poverty. This is a dual indicator under which a household is considered energy poor if they have an energy expenditure above the national median and if the remaining income after they spend that amount is below the official poverty threshold [20]. This method measures the extent of the problem; that is, the amount of energy-poor households and the magnitude of the problem – how bad each household’s energy poverty is. The indicator is represented in Figure 1. The shaded area represents the energy poor, where the households have higher than the median energy costs and income below the poverty threshold. The difference between the required energy costs and the closest threshold is the “energy poverty gap”, representing the magnitude [20].

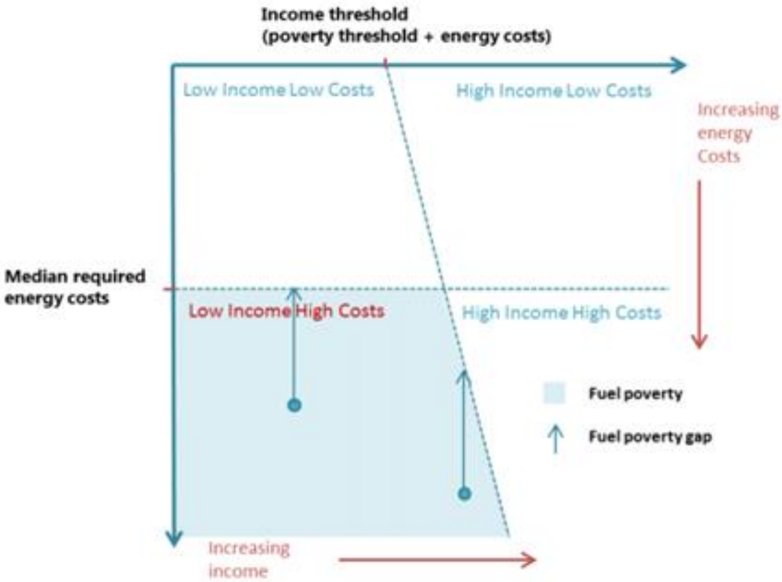

Figure 1 - Energy Poverty under the “Low Income High Costs” metric (from DECC [20])

Direct measurements, indicators based on comparing domestic energy services consumption versus a required set value. This method generally requires using temperature (and humidity) as a proxy to discern whether households maintain comfortable temperatures. For that purpose, a reference comfort temperature is used, such as the World Health Organisation (WHO) standard of 18°C–21°C [21], or those set in the national regulations. Energy services consumption can also be used in this approach.

There are often practical constraints regarding the measurement and collection of temperature and energy services datasets, which hinder the use of this approach for energy poverty assessment. The selection of an appropriate standard can also constitute a difficulty, as thermal comfort has a subjective nature, varying according to geographical, climatic, cultural, and psychological conditions [22]. As described by Thomson et al. [6], this method is rarely applied to energy poverty assessments, being used more frequently for thermal conditions in dwellings. Authors like Hong et al. [23], Kavgic et al. [24], Alevizos et al. [25] analysed indoor temperature to investigate thermal comfort and health conditions in low-income households. Other authors [26,27] have focused on energy consumption data to analyse low-income fuel poor households. Several authors, such as Calì et al. [28], Herrando et al. [29], and Kampelis et al. [30] compute the energy needs of a dwelling or a group of dwellings to analyse the gap between theoretical standard energy consumption and the actual consumption for space heating and cooling, to assess a building's energy performance. This method can also be used to analyse energy deprivation, as a buildings' energy efficiency is one of the root causes.

Other Supporting Indicators

Rademaekers et al. [15] consider another kind of approach, the outcome-based approach, which are direct measurements focusing on utility data, such as arrears and disconnections, or health outcomes, such as excess mortality in winter. The individual separation of this approach is not consensual in the literature, as, for instance, consensual-based approaches can include outcome assessment.

There are also supporting indicators that can be applied in an energy poverty assessment study, mainly to depict the different aspects influencing the issue. These indicators individually do not describe energy poverty, nor are they fit to measure it, but put together, they paint a picture of the context that might create vulnerability; therefore, being potentially valuable for helping target policy action. They can fall under several categories: Demographics; Energy demand; Income/expenditure; Outcomes; Physical infrastructure; Policy-based [15]. Examples of these indicators are number of rooms per person; dwellings in densely populated areas; dwellings equipped with air conditioning, dwellings equipped with a heating system; household size; type of family; urban/rural; available income; number of children; number of elderly people; ownership of the dwelling [15,16].

Multidimensional Metrics

The multidimensionality of energy poverty is not easily captured by a single indicator, which has led to different authors following a more integrative perspective, calling attention to the importance of considering a broader range of indicators or a combination through an index development. If energy poverty is framed as energy vulnerability, each of the six vulnerability factors (access, affordability, flexibility, energy efficiency, needs, and practices) can be expressed as a cause, driver, or outcome, which in its turn may be portrayed using an indicator [6]. By combining these indicators, a composite or multidimensional index may be created. Depending on the context, some factors might be more relevant than others, or particular factors might not cause vulnerability in that specific context, and therefore are not included in the assessment. An adequate approach would entail a combination of drivers and outcomes for a detailed evaluation of energy poverty [6]. Nevertheless, it is difficult to reflect the diversity and complexity of energy poverty using statistics without flattening the analysis and missing relevant details and aspects [8,31]. Several authors have proposed approaches that combine more than one indicator, focusing on different causes, drivers, or outcomes, such as Walker et al. [32]; Fabbri [33]; Papada and Kaliampakos [34]; and März [35].

3

Review of Fine-Scale Studies

Several approaches have been explored for measuring energy poverty at a higher spatial resolution – at the regional or local scale – across the European Union. This section reviews studies in scientific peer-reviewed literature to obtain an insight into the state-of-the-art regarding energy poverty measurement at subnational spatial scales. We focus on the different approaches and indicators used to identify the energy poor or assess overall energy poverty vulnerability in area-based methods while taking note of the data sources and datasets from which the indicators were drawn. The selected indicators are analysed for their use and utility, and innovative indicators and data sets are highlighted. Composite indicators are analysed according to their integral parts to discern the primary indicators used in their composition. The goal is to obtain an insight into energy poverty measured at smaller scales, regarding its uses and effectiveness, to devise a set of valuable understandings for local governments and organisations to support their actions and policies for energy poverty assessment and monitoring.

The analysis was divided into three pools of EU countries, following the groups for which the **EPAH call for technical assistance** was launched. This separation in geographical coverage is due to distinctions of climate, socioeconomics, energy consumption patterns, infrastructure, and energy poverty levels. The first pool is Central and Eastern European countries, the second pool is Western and Northern Europe, and the third pool is Southern Europe.[1]

A total of 48 different studies were identified and analysed. The majority of studies focus on Southern European countries – Portugal (6), Spain (9), Italy (5), and Greece (9). This group of countries is particularly vulnerable to energy poverty, as evidenced by the EU-SILC indicators, proxy indicators of energy poverty. The Western and Northern European pools are represented by eight studies – Austria (2), Belgium (1), France (1), Ireland (1), Germany (1), and the Netherlands (2), which rises to 17 if the nations of the United Kingdom are included, with 3 from England, 3 from Scotland, 2 from Northern Ireland and 1 from Wales. Case studies focusing on the United Kingdom should be considered, since this country has been looked at as a leader in energy poverty assessments due to a longstanding tradition of recognising this issue [19]. Within the United Kingdom, a range of different studies focusing on the measurement of this phenomenon in the last decades has been developed. Different metrics have been proposed and used for informing policy schemes that tackle this problem at different spatial scales. From the Central and Eastern European pools, it was challenging to find studies addressing measurement at smaller scales – 6 studies were identified and assessed: 5 from Poland, 1 from North Macedonia, and another from Romania. These numbers consider studies that focus on locations in different countries in the same study, thus amounting to a higher number than 48. Table 1 displays the analysed studies per country. Figure 2 presents the number of studies focusing on each European pool. Most authors of the reviewed studies agree on the importance of looking at energy poverty through a magnifying glass, understanding the geography of patterns, what relates to the influence and impact of the different drivers, the characteristics of the energy-poor population, and the nuances of the complex landscape regarding climate, location, infrastructure, and politics and governance [13,36]. An analytical background supported by the study of geographic context and vulnerability at smaller scales is paramount when tailoring local support initiatives and policies [13].

[1] Central and Eastern Pool: Slovenia, Slovakia, Romania, Poland, Lithuania, Latvia, Hungary, Estonia, Czech Republic, Croatia, Bulgaria. Western and Northern European Pool: Sweden, Netherlands, Luxembourg, Ireland, Germany, France, Finland, Denmark, Belgium and Austria. Southern European Pool: Spain, Portugal, Italy, Greece, Cyprus, Malta.

Table 1 - Analysed studies per country

Regional pools	Country	Studies
Southern Europe	Greece	Papada and Kaliampakos [34]; Papada et al. [37]; Boemi et al. [38]; Papada and Kaliampakos [39]; Papada and Kaliampakos [40]; Ntaintasis et al. [41]; Boemi and Papadopoulos [42]; Antepara et al. [43]; Spiliotis et al. [44]
Southern Europe	Italy	Fabbri [32]; Besagni and Borgarello [45]; Camboni et al. [46]; Bardazzi et al. [47]; Fabbri and Gaspari [48]
Southern Europe	Portugal	Antepara et al. [43]; Gouveia et al. [11]; Simões et al. [49]; Gouveia et al. [50]; Horta et al. [51]; Panão [52];
Southern Europe	Spain	Antepara et al. [43]; Sanchez-Guevara et al. [53]; Martín Consuegra et al. [54]; Aguilar et al. [55]; Sanchez et al. [56]; Alba-Rodriguez et al. [57]; Castaño-Rosa et al. [58]; Carrere et al. [59]; Stojilovska et al. [60]
Western and Northern Europe	Austria	Stojilovska et al. [60]; Einsfeld and Seebauer [61]
Western and Northern Europe	Belgium	Meyer et al. [62]
Western and Northern Europe	France	Stojilovska et al. [60]
Western and Northern Europe	Germany	März [35]
Western and Northern Europe	The Netherlands	Mashhoodi et al. [13]; Longa et al. [63]
Western and Northern Europe	England	Fahmy et al. [64]; Robinson et al. [65]; Robinson [66]
Western and Northern Europe	North Ireland	Walker et al. [32]; Walker et al. [67];
Western and Northern Europe	Republic of Ireland	Kelly et al. [68]
Western and Northern Europe	Scotland	Baker et al. [69]; Morrison and Shortt [70]; Changeworks [71].
Western and Northern Europe	Wales	Gordon and Fahmy [72]
Central and Eastern Europe	North Macedonia	Stojilovska et al. [60]
Central and Eastern Europe	Poland	Sokolowski et al. [14]; Lis et al. [36]; Sokolowski et al. [73] Frankowski et al. [74]; Karpinska et al. [75];
Central and Eastern Europe	Romania	Neacsa et al. [76]

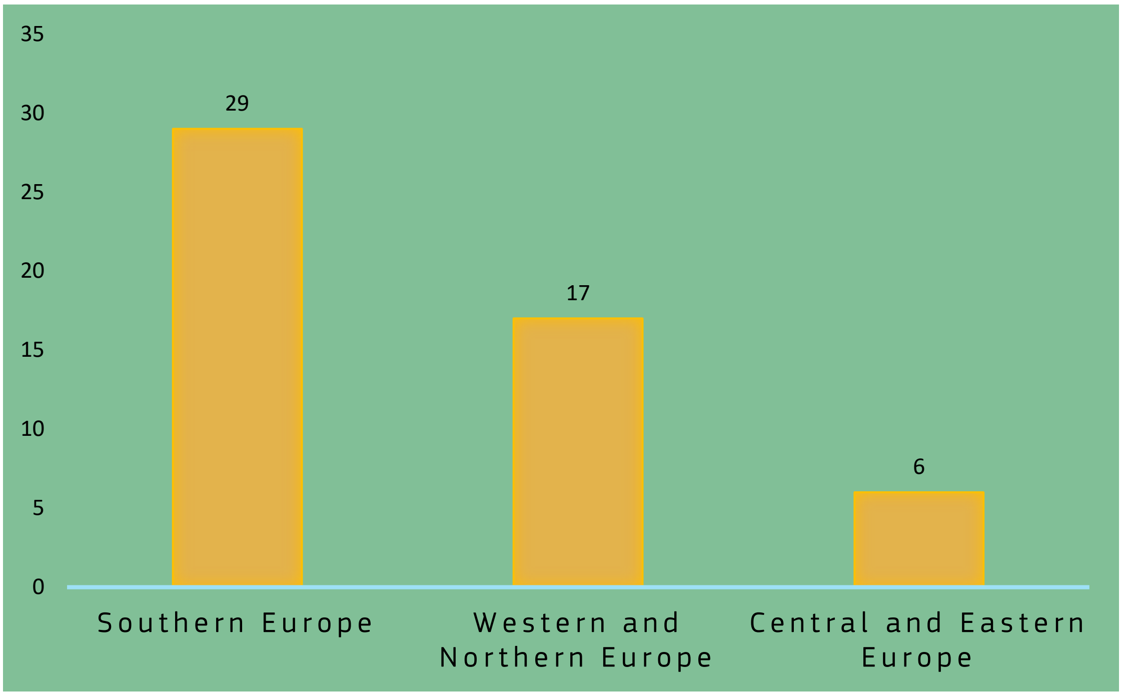

Figure 2- Number of studies assessed per European pool

3.1. Data Sources

The availability of adequate data is vital for obtaining information on energy poverty vulnerability at the level of small areas, namely on the varying nature and magnitude of its determinants. This knowledge can inform local policies and programmes for addressing areas in greater need – the highest incidence and extent of energy poverty – and improve the effectiveness of the use of resources [64]. The efficacy and effectiveness of instruments depend not only on the adequate identification of vulnerable people but also on matching the type of support to the characteristics of the people in need [36,77]. Nevertheless, the lack of data remains one of the hardest challenges in energy poverty measurement, both at a macro or local scale [8,35]. Data availability considerably shapes the studies at minor scales, as observed in this review. As März [35] affirms, using alternative supporting indicators is a way to bypass the lack of data for pinpointing the energy poor. However, not every proxy indicator is comprehensive enough to help study the complexity of energy poverty.

A considerable diversity of datasets was identified in the reviewed studies. Still, most of the analysed studies rely on some kind of official statistics from one or more state or governmental entities. Census data are among the most used datasets in these assessments, being used for case studies in the Southern (Portugal, Spain, and Italy) and Western and Northern European pools (Germany, England, Scotland, and Wales). The national statistics office often provides census data disaggregated by administrative units for some countries at a very small scale; for instance, in England, the recommended size is 125 households for each output area. The census statistics feed a diverse range of indicators, from socioeconomic to building stock envelope and equipment characteristics, often used as energy poverty proxies in the analyses. In fact, in the scope of a census, there is no data collection to directly inform a specific indicator aimed at measuring energy poverty, as official definitions are still scarce. An important limitation of census data is the frequency it is collected – these statistics are only collected every 10 years. Some indicators, such as unemployment and sociodemographic conditions, become outdated quickly. For building data, as changes in that particular sector are bound to be slower, they still hold value after a few years.

National household budget surveys (HBS) are also a very common source of data used in these studies, releasing data every five years on energy consumption (e.g., consumption levels, equipment ownership) and expenditure, often used in energy poverty measurements. This was used in countries in all three European pools, namely England, Italy, Portugal, Poland, Spain, and Scotland. These are conducted with a representative sample of people from across each country. Results are given at the national or NUTS2 level; hence, it only enables regional analysis and not local. Nevertheless, they often combine useful socioeconomic indicators with dwelling information at the household level [52,75], which can be used to understand correlations between variables. HBS are also used to collect qualitative data on the households' perceived thermal comfort and dwelling conditions, which are the cornerstone of consensual-based energy poverty indicators [36,75].

Conducted in a similar way to the HBS, the Energy Consumption Survey (ECS) also provides valuable information on household energy consumption broken down by energy use – generally collected every five years. This is utilised in studies that apply direct measurements of energy or performance gaps to identify the energy poor, as demonstrated by Gouveia *et al.* [11] and Karpinska *et al.* [75]. For Spain, Sanchez *et al.* [56] argue that there is limited official statistical data regarding energy-poverty-related indicators, pointing out issues in data disaggregation, update, and the discontinuity of indicators, which mainly apply to surveys such as those mentioned above. These issues pose a challenge for tracking the evolution of the problem. This review makes it apparent that most of these assertions are valid for other European countries. Furthermore, the authors defend the need for a dedicated energy poverty section in existing surveys to improve statistical resources.

Eurostat is also a reliable data source, namely the European Union Statistics on Income and Living conditions, providing longitudinal and cross-sectional proxy indicators of energy poverty at the NUT2 level for the EU Member States, which can be valuable for regional assessments, as in Meyer *et al.* [62]. This database also provides socioeconomic data at the same scale. Although the authors rely primarily on national official data sources, EU SILC and other Eurostat data have been used in Spanish [54,57,58], Greek [34,40], and Dutch case studies [13], mainly regarding income and energy prices. A critical advantage of the Eurostat database is that it provides comparable data between the Member States. Although HBS are conducted in virtually all EU Member States, questionnaire methodologies might vary across countries, and the harmonisation of categories is not ensured; hence, the results are not so easy to compare.

At the national level, energy prices and consumption levels are occasionally collected from energy providers [41]. Income is often withdrawn from official sources but can also be available in market studies [76]. Climate data such as heating and cooling degree days or season and average outside temperatures are also used and are generally obtained from national entities, such as meteorological institutes. These provide local data from available climate stations in every country (as in Mashhoodi *et al*. [13]; März [35]; Lis *et al*. [36]; Spiliotis et al. [44]; Walker et al. [32]). Regulations on the energy performance of buildings (Gouveia *et al*. [11]; Besagni and Borgarello, [45]; Simões *et al*. [49]) and energy modelling software [57,58] are also used as a source of climate data. Other national and regional or local entities can also supply climate information, as can European databases like Eurostat and the Commission Joint Research Centre, the latter providing data for Bardazzi *et al.* [47].

Apart from the census and national surveys, or other statistical authorities, building data is occasionally collected from studies in literature and academia [11,49,57] including the regulations on energy in buildings [44], and energy modelling software (*e.g.,* Fahmy *et al*. [64]). Energy performance certificates (EPC) are an essential source of building and equipment data used in some studies [46,71], although there are often some constraints regarding its use due to confidentiality issues. Some municipalities are responsible for managing the energy performance certificates for buildings, which makes it possible for their data to be disclosed for research purposes [48] or used in their own energy poverty assessments.

It is important to highlight a very relevant data source for several of the analysed studies – surveys conducted by the researchers or authors themselves. These surveys or interviews conducted explicitly to assess energy poverty can be less ambiguous and more prepared to capture the different facets of the issue. They enable collecting different types of indicators, from self-perception of the cold or warmth to building characteristics and socioeconomic features. In this kind of survey, health indicators such as doctor visits, disease rate, and types of health problems are collected to analyse energy poverty impacts on the population [14,34,38,40,45, 59]. These surveys also collect data on energy behaviour, coping strategies, and heating periods [34,42,45]. Castaño-Rosa *et al.* [58] and Alba-Rodrìguez *et al.* [57] introduced a thermal comfort assessment using survey data. Such surveys are an effective tool to overcome difficulties in accessing adequate data or the lack of data but require expertise and resources. The quality of these results is highly dependent on interviewee answers, which introduces the factor of unpredictability and error. If conducted periodically, at least yearly, they can track energy poverty levels more frequently instead of relying on outdated national statistics. Several authors of the viewed studies have resorted to their own or research specific surveys to support their work, such as Boemi *et al.* [38], Gouveia *et al.* [50], Boemi and Papadopoulos [42], Sokolowski *et al.* [14], Stojilovska *et al.* [60], Eisfeld and Seebauer [61]. The use of such tools is transversal to all three European pools. Table 2 shows the main indirect data sources identified for the countries with more studies reviewed.

Table 2 - Data sources by indicator type in selected European countries

Macro -area	Indicators	UK (England, North Ireland, Scotland, Wales) + Ireland	Greece	Italy	Poland	Portugal	Spain	Netherlands Germany, Austria
Climate	Heating and cooling degree days	-	Hellenic Statistical Authority; Hellenic National Meteorological Service - open source	EU Commission Joint Research Centre database	-	Buildings energy performance regulation; Portal do Clima; municipal energy agencies	CCWorldWeatherGen (software);	Royal Netherlands Meteorological Institute; German Meteorological Service
	Average outside temperatures	Census 2011; Met' Eireann (North Ireland); Meteorological Office; Land and Property Services	-	Buildings energy regulation	Institute of Meteorology and Water Management (CSO)	Buildings energy performance regulation	International Weather for Energy Calculation (Energy Plus); MODIFICA project; Madrid Urban Climate report	-
	Climate zones	-	Greek legislation - Technical Chamber of Greece, Technical Instruction	-	-	Buildings energy performance regulation	-	-
Facilities/ housing	Building stock characteristics (physical features; year of construction; space heating and cooling systems) and thermal parameters of the envelope	Living in Wales survey (2004); Census 2001; Building Energy Rating Certificate (BER) of Sustainable Energy Authority of Ireland (SEAI); Census 2016 – Theme 6; Large Scale vector and Pointers dataset from Land and Property Service (Northern Ireland); Buildings Research Establishment Domestic Energy Model (BREDEM-12);2003; English House Condition Survey; Council data (Scotland); Scottish EPC register; LUCID (Local Urban Climate Model and its Application to the Intelligent Design of Cities) project; EPCs; Taylor *et al.* [78]	Hellenic Statistical Authority, Eurostat; Observatory of Greece; Greek legislation; Technical Chamber of Greece, Technical Instruction 20701-1/2010; Greek energy efficiency regulations (TEE-KENAK, 2019); TABULA; De Rosa *et al.* [79];	Italian Statistical Office (ISTAT) Database from Census 2011; HBS; Madonna [80]; EPCs; Census 2011; National module of SILC by ISTAT; HIPERBOLE database	HBS; ECS	National Statistics of Census (2011); Energy performance certificates; Energy Technology Systems Analysis Programme (ETSAP); Lopes [81]; HBS	Census 2001 and 2011; Spanish Energy Efficiency legislation; Spanish Land Registry	Census 2011; KWB - Statistics Netherlands (CBS); WoonOnderzoek Nederland' (WoON)
	Energy consumption or demand	-	Hellenic Statistical Authority; Utility/energy provider, natural gas company; Center for	EPCs - SACE regional Database; Census 2011; Italian Regulatory Authority for Energy,	ECS;	ECS; HBS; smart meters; National Directorate for Energy and Geology	DesignBuilder software - energy simulation of buildings; IDAE - Consumption of the	KWB - Statistics Netherlands (CBS); WoonOnderzoek Nederland' (WoON); Heating atlas of the city of Oberhausen

			Renewable Energy Sources and Saving	Networks and Environment			Residential Sector in Spain - Institute for the Diversificatio n and Savings of Energy; CE3_Vivienda s for the energy simulation of buildings;	
	Households experiencing cold or warmth	English House Condition Survey	-	EU SILC	HBS;	-	Barcelona Public HealthSurvey (BPHS)	EU SILC
	Energy expenditures	RdSAP software - Standard Assessment Procedure; Department of Climate Change	-	HBS; EU SILC	HBS; ECS; Central Statistical Office of Poland	HBS	HBS;	EU SILC
	Energy/fuel prices	Domestic Fuels Comparison of Energy Costs – Sustainable Energy Authority of Ireland (SEAI); enquiry of oil suppliers; Buildings Research Establishment Domestic Energy Model (BREDEM-12)	Ministry of Infrastructure, Transport, and Networks - Fuel Prices Observatory; Ministry of Development, Competitivenes s, Infrastructure, Transport, and Networks; open-source services; utility provider.	Italian Regulatory Authority for Energy, Networks and Environment.	-	-	-	Statistics Netherlands (CBS); Eurostat;
Socioeconomic	Income	Living in Wales survey; Census; NINIS Neighbourhood Statistics (Northern Ireland); Department for Energy and Climate Change, Fuel Poverty Sub-Regional Statistics: English Housing Survey; Census; Scottish House Conditions Survey;	Hellenic Statistical Authority; Papada and Kaliampakos [82]	ISTAT Database from Census; HBS; EU SILC; HIPERBOLE database	HBS	Census; National Statistics; HBS	HBS; Eurostat; Madrid Municipal Census; Madrid city statistics	EU SILC; KWB - Statistics Netherlands (CBS); WoonOnderzoek Nederland' (WoON),
	Other sociodemogra phic and economic indicators (*)	Living in Wales survey; Census; NINIS Northern Ireland Neighbourhood Information Service; English Housing Survey; Scottish Housing Conditions Survey	-	ISTAT Database from Census 2011; HBS; EU SILC	HBS; Local Data Bank;	National Statistics; Census;	Census; Madrid city statistics;	Atlas; Social Structure Atlas; KWB - Statistics Netherlands (CBS); WoonOnderzoek Nederland' (WoON),

(*) or more of the following: dwelling tenure; education level; age of the population; social benefits recipients; employment status; number of children; number of elderly; degree of urbanisation; gender; household composition; household occupation; profession; people with disabilities; changes in economic resources; marital status; absolute poverty; population density; means of transportation; urban/rural location; number of occupants of dwelling; household structure.

3.2. Indicators and Methods

As previously mentioned, experts argue in favour of approaches that assess the array of dimensions that characterise energy poverty, bringing in and combining a variety of indicators to more thoroughly capture the complexity of this social issue at different scales [9,83]. This is further evidenced by the Covenant of Mayors for Climate and Energy in Europe, with the support of EPAH and the Joint Research Centre, which has recently proposed a set of indicators for assessing and monitoring energy poverty at the local level, including several macro-areas, namely climate, facilities and housing, mobility, socioeconomic factors, policy and the regulatory framework, and participation and awareness-raising. The Covenant of Mayors signatories have committed to "providing access to secure, sustainable and affordable energy for all", and alleviating energy poverty is part of the solution [84]. Several authors of the analysed studies shaped their assessments according to the available data, whilst others collected their own data through surveys and questionnaires. The same applies to scale – different spatial scale resolutions are explored in the reviewed works, from NUTS2 to very small scale like the Lower Layer Super Output Areas in the UK. The smaller the scale, the more specific and potentially hard-to-get the data is. Most studies have focused on energy poverty in the heating season, relying on indicators that portray heating consumption, expenditure and habits, and winter vulnerabilities.

The methods applied in the reviewed studies are considerably diverse. Various authors adopted the traditional expenditure-based metrics, well established in the literature, such as the 10% threshold of income spent on energy and the Low-Income High-Cost indicator, developed in the UK. In fact, in UK case studies, such as those by Fahmy *et al.* [64], Robinson *et al.* [65], and Changeworks [71], this kind of indicator is still used for disaggregated assessments. These are indicators that have been historically used to capture the economic vulnerability of households. Outside of the UK, some authors in Southern Europe transferred these indicators to their specific contexts, such as Panão [52], Lis et *al.* [36], Sokolowski *et al.* [14] and Sokolowski *et al.* [73] in Poland; Aguilar *et al.* [55] in Spain; Ntaintasi *et al.* [41] and Spiliotis *et al.* [44] in Greece. Panão [52] in Portugal and Aguilar [55] in Spain compared the number of people identified as energy poor with several expenditure indicators. Even when considering only one dimension of the problem, in this case, the economic dimension, the use of different indicators might result in the identification of different people. The 10% indicator, using a fixed threshold, provides a more binary and homogeneous distribution of energy poverty vulnerability, although it is susceptible to the energy price driver [52; 65]. Ntaintasi *et al.* [41] and Spiliotis *et al.* [44] used this threshold to mark the frontier between energy poor and non-energy poor for Greece. It should be noted that this indicator was tailored according to the British context and society, potentially not being as suitable for other contexts [6]. Indicators such as "2M", "M2," and "LIHC" use relative thresholds; thereby, avoiding this problem as they represent the reality of each context. Nevertheless, due to the relative thresholds, these indicators might falsely identify energy poor in high-income groups or non-energy poor in a very low-income group [52,65]. To use these indicators, the authors required income data, energy prices, and energy expenditures using indicators for income and energy prices and/or energy expenditures.

A large part of the authors developed quantitative, multidimensional approaches capturing more than one dimension of vulnerability, such as Gouveia *et al.* [11], Martìn Consuegra *et al.* [54], Sanchez *et al.* [56], Castãno-Rosa *et al.* [58], Alba-Rodriguez *et al.* [57]; Karpinska *et al.* [75], among others. They use groups of indicators representing climate, building characteristics or energy performance, energy consumption and HVAC equipment, energy prices and expenditures, socioeconomic features of households, such as income, age, or employment status, encompassing the three main causes of energy poverty. Gouveia *et al*. [11] calculate a vulnerability level for all civil parishes of Portugal, identifying hotspots of vulnerability. Martìn Consuegra *et al.* [54] combine indicators to study the severity of energy poverty in deprived neighbourhoods in Madrid, aiming to establish priority areas for refurbishment. Castãno-Rosa *et al.* [58] and Alba-Rodriguez *et al.* [57] use a composite assessment considering monetary, energy consumption, and thermal comfort indicators and a Health-Related Quality of Life Cost analysis to assess energy poverty vulnerability for case studies in Spain. For Madrid, Sanchez *et al.* [56] used several indicators to calculate energy poverty incidence, identified the most important indicators at city level, and then drew conclusions using proxy indicators at the district level. Karpinska *et al.* [75] first calculated energy prevalence with expenditure and energy consumption indicators and then used a varied set of indicators to explain and identify different profiles of energy poverty at the local scale.

These authors combine the analysed indicators in distinct ways and with varying levels of complexity: some conduct a direct comparison of indicators, some build linear mathematical models, deterministic by nature, while others advance statistical analyses trying to estimate the probability of certain outcomes. Each method is selected according to the study's goal and the type of outcome the authors aim to obtain. Most statistical approaches provide analysis on the predictors and estimates of local prevalence. They enable data-driven multivariate analysis that captures the complex origins of energy poverty, discerning the most impactful determinants and how they relate to one another. They allow a systematic assessment of the problem. Longa *et al.* [63] point out that this kind of approach provides an established and transferable methodology to estimate the weight of each energy poverty determinant, a research gap identified by Walker *et al.* [32], who states that drivers are often assessed using the intuition or common sense of the authors or consulted experts or predefined models.

Within the statistical field, machine learning models have advantages compared to traditional regression models, as they are more equipped to handle big data sets. They do not necessitate prior assumptions on the correlation of factors and can deal with non-linear dependencies, which is important when studying complex issues such as energy poverty [63]. Replication of these models to other contexts is also possible. Nevertheless, they are complex to build and analyse, requiring expertise that may not be at hand for local governments or organisations. On the other hand, looking at the other side of the spectrum, deterministic approaches supported via assumptions can be simpler to apply and allow for a broader range of parameter testing, although these are potentially less replicable and scientifically sound.

In either of the two approaches, the quantitative outcome of the model (*i.e.,* being in energy poverty) can assume different forms, from a binary representation to a range of values, as definitions of energy poverty are still lacking and often do not define a quantitative measure. Thresholds are often used to characterise the dependent variable and divide the energy poor from the non-energy poor. Different thresholds can significantly impact the exercise of identifying the energy poor and assessing its magnitude [63]. Therefore, they have considerable influence in policy instruments if these methods are to be used for policy formulation. On the other hand, a range of values avoids this constraint, but meaning has to be attributed to the values, a meaning that translates to a real application.

These types of measures enable the use of proxy indicators that are frequently available in national statistics, making up comprehensive assessment frameworks and offering important insights. Proxy indicators for which available data exists help overcome the lack of important datasets, which as pointed out by Sanchez *et al.* [56] is a common issue in finer spatial scale assessments. Some authors resorted to datasets and sources not common in energy poverty assessments, which can be considered proxy indicators, standing as effective alternatives. An example of this instance is the use of the property value of buildings as a proxy of the economic status of their occupants or housing quality [63,64,65]. Walker *et al.* [67] associated the number and type of retrofits with energy poverty risk. Neacsa *et al.* [76] associated renewable energy potentials with lower energy poverty vulnerability. Frankowski [74] collected data online on smog alerts, initiatives, news, and organisations to analyse Poland's air pollution and energy poverty issues through online research and interviews.

Meyer *et al.* [62] state that monitoring energy poverty requires the analysis of its extent (number of affected households) and depth (magnitude) and that these two factors are essential for policymakers to formulate instruments and decide on their actions [62,85]. To consider the different forms of energy poverty – measured energy poverty (excessive expenditures) and hidden energy poverty (abnormally low energy expenditures) – is also something crucial so as not to leave anyone out of the picture when it comes to energy poverty assessment and ultimately in providing aid. Other authors, such as Sokolowski *et al.* [73], follow a similar approach that considers intensity and headcount in their deprivation assessment.

Several authors, such as Gouveia *et al.* [11], Robinson *et al.* [65], and Morrison and Shortt [70], use GIS data to map results supporting visualisation and better spatial understanding. Georeferenced data enables the mapping of energy poverty estimates, and thus the identification of “cold” and “hot” spots of energy poverty, which is the basis for zonal policy approaches, where certain areas are targeted to receive greater support than others based on differences in vulnerability [35]. It also enables clustering analyses to identify the geographical context – if it is an outlier zone (“hot” in “cold” area or “cold” in “hot” area) or part of a homogeneous landscape of vulnerability, as described by Robinson *et al.* [64] and Walker *et al.* [32].

Some authors, such as Stojilovska *et al.* [60], collect qualitative data through surveys and questionnaires and analyse it qualitatively (i.e., non-numeric information) exploring the link between household characteristics, decisions and behaviours, and energy poverty incidence. However, approaches that rely on quantitative and qualitative data collected through surveys are more common, especially in Southern European studies. Qualitative indicators generally pertain to the self-experience of households regarding thermal comfort, health, coping mechanisms, and behaviours. Various authors [14,38,42,47,61,64] collected data for quantitative and qualitative indicators, generally developing statistical analysis using categorical and numerical variables; that is, using both types of indicators or a mathematical formula where indicators are standardised and weighted. For instance, Sokolowski *et al*. [14] created a five-indicator framework composed of two objective and three subjective indicators, with cut-off points resulting in a weighted level of energy poverty. Bardazzi [47] also calculated five indicators of energy poverty, two consensual-based and three expenditure-based, and performed a multivariate analysis using other indicators as determinants or independent variables representing income inequality and socioeconomic conditions, as the goal was to explore the connection between energy poverty, income inequality, and socioeconomic factors. Boemi *et al*. [38] collected quantitative (income, building characteristics, socioeconomic) and qualitative indicators (self-perceived thermal comfort, arrears on utility bills, energy measures implementation) to relate energy poverty, education level, and energy behaviour in the economic crisis in northern Greece. Boemi and Papadopoulos [42] used the two types of indicators informed by collected questionnaire data to study the relationship between energy poverty and health impacts and the adoption of energy efficiency measures. Einsfeld and Seebauer [61] used income, expenses, and subjective indicators regarding heating behaviours and environmental concerns to investigate whether energy-poor households are overlooked due to self-restrictive heating. For England, Fahmy *et al*. [64] also used quantitative (income, energy prices, energy costs, building data) and qualitative subjective indicators to investigate the better predictors of energy poverty in a regression analysis and predict the odds of a household being energy poor.

Horta *et al.* [51] divide their analysis into two parts: quantitative, to identify the most vulnerable locations, and qualitative, where interviews are conducted with households selected from the vulnerable areas. As discussed previously, the geography of energy poverty is highly sensitive to the type of measure or metric used to assess it [64]. Authors have found limited overlap of objective (based on energy expenditure) and subjective indicators [62,64,86] of the incidence of energy poverty. Dubois *et al.* [87] propose that this is due to the rationing of energy consumption by people that claim to be in energy poverty, but Meyer *et al.* [62] affirms that this hidden energy poverty can only partially justify the limited overlap, thus stating that people are claiming to be energy poor that are not detected by the objective expenditure measures analysing measured and hidden energy poverty. This emphasises the importance of considering both types of measures in energy poverty assessments.

As even aggregate models still fall short of encompassing all the facets and dynamics of energy poverty in every geographical area, approaches that are adapted to local characteristics and specificities of culture, habits, sociodemography and economy are necessary, but adequate indicators must be included for a comprehensive technical analysis [14]. This becomes evident when looking at the varying results of the analysed case studies across Europe. Building on the statement by Meyer *et al.* [62], it is necessary to consider not only measured and hidden energy poverty but also experienced energy poverty, which has important variations at smaller scales. Subsequently, strategies to tackle energy poverty should vary across locations [36]. Although there are several analyses that compare countries at the national level, only a few authors conduct analyses of energy poverty incidence or determinants across different contexts in several countries, such as Stojilovska *et al*. [60] and Antepara *et al*. [43]. If these provide in-depth nuanced analysis, the findings are valuable for comparing the energy poverty configurations in different geographies. Such analyses can be similar for different contexts, opening the possibility for knowledge transfer, which can enable effective solutions to be more rapidly tested or adopted.

Robinson *et al.* [65] and Morrison and Shortt [70] warn of the ecological fallacy in area-based approaches, as aggregated area-based data can hide variations of energy poverty vulnerability at even smaller scales, namely at the neighbourhood level. Kelly *et al.* [68] corroborate this assertion, stating that aggregate and average data mask issues, and that finer spatial scales are preferable from social and policy perspectives. It is possible to identify a trade-off situation, where small-scale analysis should be prioritised, but the finer the scale, the lower the amount of data available, as there are issues in data sourcing in European countries at finer spatial scales. Ultimately, data availability is the key to improved disaggregated energy poverty assessments.

Takeaways from the European Pools

- The majority of the reviewed studies are from Southern Europe.
- Central and Eastern Europe is underrepresented, with a small number of studies.
- Several authors still support their assessment in expenditure-based metrics in all three pools.
- Income is the most widely used indicator in every pool.
- There is a great variety of socioeconomic indicators collected from different sources, especially from national statistics.
- In studies from the Western and Northern pools, energy prices are used more in energy expenditure approaches.
- Building data is widely used but mostly in Southern European studies with a greater level of detail.
- Climate indicators are primarily used in Southern European studies.
- There is a variety of multidimensional metrics, primarily for Southern Europe.
- Most studies in every pool rely on disaggregated national statistics, mainly census, Household Budget Surveys, and Energy Consumption Surveys.
- Authors using their own survey-based approaches exist in all three pools, particularly in the Southern European pool.
- Statistical analyses predicting the incidence of energy poverty and analysing the correlation of determinants are prevalent in the Western and Northern pools.
- A mix of qualitative and quantitative indicators are mostly used in Southern European studies.
- Spatial resolution varies from NUTS2 to district, and most studies focus on one specific region or location in a country. However, a few authors developed disaggregated studies in each of the three European pools for the whole country.

4

Unexplored Indicators and Data Sources

The digitalisation of the energy sector assumes a pivotal role in reducing energy poverty while increasing resource efficiency, promoting the energy transition, and decarbonising the economy. Solutions should increasingly rely on cutting-edge technology supporting decentralisation, decarbonisation, and digitalisation, promoting the shift from an energy monopoly to an energy democracy. A digital energy system encourages the distribution of energy resources, the flexibility of loads, variability of the system, the more active role of consumers in managing their energy supply, and even greater energy efficiency and costs. Emerging technologies such as the Internet of Things, blockchain, artificial intelligence, machine learning, and big data are crucial in this transformation.

They are responsible for the function and automation of these systems, being the fabric of the network between producers and consumers, stakeholders and devices. Simultaneously, large amounts of relevant trusted data are collected, which can be used in other contexts, such as energy poverty measurement studies, granted that confidentiality issues are accounted for [88]. Big data is collected through various Internet-of-Things devices such as smart meters, building automation systems, sensors, thermostats, and mobile devices. In households, these can be used to collect data on indicators of temperature, humidity, occupation, and energy consumption. From among the research works reviewed here, only one [50] used smart meter data directly to study energy poverty, particularly for cross referencing electricity consumption profiles with socioeconomic data and building energy simulation to identify energy-poor groups for the 265 households. Electrical consumption data from smart meters have very high temporal resolution and can be very useful for studying consumption patterns and consumer profiles from the perspective of energy poverty vulnerability, especially when electrification is an EU goal for achieving carbon neutrality.

Energy Performance Certificates (EPC) data has been used for several studies describing building stock and its energy needs. EPC data are drawn to study building energy use and consumer profiles, rarely integrating the bigger perspective of energy poverty assessments. As EPC schemes are continuously enforced in the European Union, with the subsequent ongoing data collection (at least 24 Member States have established EPC registries) [89], the potential of this data source is increasing. For studies assessing energy poverty at finer scales, only 3 studies were found – Changeworks [71] for Scotland, and Camboni *et al.* [46], and Fabbri and Gaspari [48] for Italy using EPC data. As building stock energy performance is one of the root factors determining energy poverty, EPC datasets, which are by nature disaggregated per territorial unit, can be valuable for informing energy poverty assessments, providing information on the building stock characteristics and thermal performance at higher spatial resolution, which is rare. Nevertheless, sourcing these two datasets, EPC and smart meters, is still a strenuous challenge due to the European General Data Protection [68] protecting the data confidentiality rights of consumers. The entities responsible for managing them are conscientious when it comes to sharing data, even for research purposes.

Citizen science is another untapped source of data emerging in natural science, which has significant potential. ENGAGER [90] points to its important role in new research approaches and more participatory and democratic forms of knowledge production. As it assumes more relevance, these sources of data can fill gaps in official datasets, particularly regarding qualitative indicators. In their study, Frankowski *et al.* [74] show how citizen science data, namely smog alerts, can be leveraged to explore the connection between air pollution and energy poverty.

There are various official data sources, but since datasets are collected using different methods and in differing forms, it is always a challenge to combine them and not introduce an unreasonable percentage of uncertainty to the assessment that could jeopardise its scientific soundness. This is a difficult gap to overcome because it is an issue at the source, depending on decisions from the policymaking side. Camboni *et al.* [46] propose a method to match different sources of information at the micro-scale (EPCs and socioeconomic from administrative sources) for identifying areas at risk of energy poverty. This is an example of a method confronting the considerable barrier of official data harmonisation. Further investigation on this topic, namely on transversal approaches, could prove helpful for the multi-source comprehensive analysis of energy poverty, as changing the political *modus operandi* is often an arduous endeavour.

Furthermore, it is important to highlight the need to focus on vulnerable people, as metrics and assessments often overlook groups whose differing characteristics make them vulnerable [91]. Structural social dimensions such as disability, ethnicity, and gender and their impact on vulnerability should be researched at higher-resolution spatial scales. Robinson *et al.* [66] is a good example of a study investigating the correlation of gender with higher incidence of energy poverty.

Moreover, only a few reviewed studies focus on summertime energy poverty, mainly in Portugal and Spain [11, 49, 50, 51, 53]. With climate change, temperatures are bound to rise, and summertime cooling is becoming a more relevant issue in the energy poverty landscape [91].

In a review of energy poverty metrics, Siksnelyte-Butkiene *et al.* [92] have called attention to the need to include environmental and sustainability dimensions in hybrid approaches, which applies to smaller-scale studies. Whilst the energy efficiency of technologies and buildings are common in the reviewed assessments, indicators such as indoor and outdoor air quality and renewable energy sources, which could add relevant information to paint a more complete picture of the problem, are still underused. The only examples in the conducted review are Frankowski [74], linking air pollution with energy poverty incidence, and Neacsa *et al.* [76], who brought in renewable energy sources mapping to analyse energy poverty in Romania. Therefore, there is still ground to cover regarding the inclusion of these indicators in energy poverty assessment, especially in more spatial granulate evaluations, due to its relevant geographical dimension.

Temporal variation is also underexplored in energy poverty studies in general and particularly in local assessments. Studies generally provide a snapshot assessment, even when dealing with datasets from different periods. A few studies work with longitudinal data, like Meyer *et al.* [62], but these often focus on past periods. There is a lack of studies addressing future vulnerabilities, using data from forecasts and future scenarios to inform studies projecting future energy poverty vulnerabilities at the local level.

A paradigm shift from separately considering the satisfaction of needs and energy efficiency to the concept of well-being energy is currently being pushed forward [73], underpinning the need to address energy poverty in the context of other energy and climate goals. These can highlight the use of alternative indicators to assess energy consumption in buildings, focusing on energy sufficiency – the amount of energy necessary for thermal comfort and well-being, instead of considering energy as a separate unit from well-being, from the perspective of supply, demand, and efficiency, which has been the practice hitherto.

On another note, and returning to the current state of local governance, local governments and agencies often design their policies and programmes based on data collected informally through multiple methods, from social services, advice points, helpdesks, surveys, online platforms for support programme applications, home visits, and other forms of contact with the population. These datasets are not to be neglected, as they facilitate the identification of energy-poor households and provide support to policy measures when other datasets are absent. The EPAH Atlas provides a few examples of local governments using and collecting their own data to support their initiatives [93]. In the Italian project "*Energia su Misura*", conducted by the local authority Comune di Milano, energy bills of families living in social housing were consulted, and smart meters were installed to engage the identified families and provide them with personalised reports and advice. The city of Sztum in Poland conducted a survey with single-family households of a specific quarter for collecting data on buildings (type, age, thermal insulation, past renovations) and socioeconomic data (income, age, number of people), which will be used for upcoming measures to reduce emissions and subsequently improve health and comfort conditions for citizens in the city. In Barcelona, the project "*Indicadors municipals de pobresa energètica a la ciutat de Barcelona*" compiled and assessed various local datasets from state surveys, local projects, social services, and energy advisory points to estimate energy poverty at the local scale in Barcelona. Finally, in Portugal, through a network of different partners, the project "*Ponto de Transição*" is assembling a one-stop-shop on an old maritime container to collect data and provide energy advice for the residents of three municipalities from the greater Lisbon area, as well as providing training to young agents, who will conduct home visits for even more personalised support to households in need.

While the goal of this report is not to conduct a review of available local governments datasets, which is best done by representatives of each national context due to the language barrier, the aforementioned projects highlight how collecting data and even repurposing already collected data can be so relevant for local governments in identifying and targeting the vulnerable population and ultimately shaping policy and other interventions. There is potential for local governments to further tap this data source. This review uncovers the data and indicators used in the research, which do not represent the totality of data available, as evidenced by the mentioned projects. The uncovered resources and metrics are meant to expand and strengthen the database available to local governments, joining them to the local datasets that these entities have at their disposal. It is worth mentioning that other local data produced by civil society and non-government organisations (NGOs) can also be of value to local governments. The combination of research data and methods, national and regional statistics, and local datasets from local governments, organisations, and civil society can form a comprehensive kit of resources to support the tailoring of effective interventions towards reducing energy poverty at the local level.

5

Recommendations for Policymaking

The review conducted herein highlights important challenges and considerations regarding the measurement of energy poverty at more local scales. From these findings, several recommendations for local governments and organisations can be formulated:

Identify the available datasets from official sources

Before assessing and selecting which metric to apply, it is important to survey the existing datasets disaggregated at the aimed local scale, stemming from national and regional authorities, pertaining to the most commonly used indicators for energy poverty assessment.

Repurpose local data

Local governments often collect data for other purposes in specific services such as advice points, helpdesks, social services, and for grants and financial support provided to households. These data can be used for energy poverty studies.

Investigate alternative local science data

There are underused and less-known datasets from sources such as civil society and NGOs whose integration can be advantageous.

Collecting own data

If data availability is a considerable barrier, impeding a comprehensive assessment of the different aspects of vulnerability, collecting data through surveys and questionnaires is a good way to obtain relevant information on consumers. Although it can require substantial time and investment, it has several advantages, providing information specific to the case study.

The right method for the right data

Depending on the available data or data to be collected, and also on what is being measured, choosing the most suitable method is key for a balanced and sound approach. Expenditure-based methods require data on income, energy prices, and real energy consumption. Consumption thresholds ask for modelled energy consumption, which requires building thermal characteristics, climate data, and consumer behaviour. For approaches based on qualitative and subjective indicators, the self-perception of households has to be collected via appropriate surveys or questionnaires.

Focus on all the dimensions of energy poverty

When identifying and analysing the energy poor or energy poverty vulnerability in a specific location, the approach put forth must be comprehensive in its evaluation. It should combine indicators that address each of different causes of the problem: the building stock and its equipment, energy performance and efficiency, socioeconomic characteristics, and the situation of the population, thermal comfort and well-being, and environmental aspects.

Consider different indicators

Some indicators that are not frequently used for energy poverty assessments can be good proxy indicators for representing one or more of the various dimensions of the problem.

Combine quantitative and qualitative

The literature shows that there is little overlap between subjective and objective metrics results in the identified energy-poor population, indicating the great diversity of vulnerable people. If possible, it is preferable to use both types of indicators in the analysis so as not to disregard anyone.

Evaluate type, extent, and depth

A comprehensive assessment of energy poverty at all scales should preferably consider: 1) type of energy poverty (measured, hidden, and perceived), evaluated with different indicators; 2) number of people affected (extension); and 3) the magnitude of the problem in the population, which can be evaluated by calculating the difference compared to a specific threshold or any kind of value range.

Focus on both summer and winter vulnerability

Winter energy poverty has been the main target of studies, but it becomes increasingly more relevant to look at summer vulnerability, also considering future vulnerability, as the frequency of high temperatures and extreme events is already happening and predicted to rise due to climate change.

Consider mapping for visualisation

Using georeferenced data for mapping the results is a good option to pinpoint "hot" or "cold" spots of vulnerability in a territorial analysis, shaping policy accordingly.

Watch out for ecological fallacies

When conducting area-based assessments, the bigger the territorial units, the higher the possibility of hidden vulnerabilities and variations in expressions of energy poverty. Finer spatial scales are preferable to avoid masking nuances, but data availability at finer spatial scales is also an issue. It is necessary to find the best balance between these two circumstances.

Do not forget minority vulnerable groups

Official data and metrics often leave out vulnerable minorities that do not participate in the data collection process. Efforts should be made to include these groups in the assessment or even dedicate specific studies to studying them.

6

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