LOCATEE

LOCAL AUTHORITIES TACKLING ENERGY POVERTY IN PRIVATE MULTI-APARTMENT BUILDINGS

Analysis of Indicators and Datasets for Energy Poverty Assessment: The Case of Private Multifamily Buildings

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About LOCATEE

LOCATEE aims to support local municipalities in addressing energy poverty through the renovation of private multi-apartment buildings for vulnerable residents. LOCATEE will achieve this goal by providing a toolkit for identifying energy-vulnerable households, matching tailored interventions to their needs, and integrating energy poverty alleviation activities into long-term strategies of municipalities such as Sustainable Energy and Climate Action Plans. LOCATEE will use administrative data to create household and building typologies to identify priority intervention locations. This process will help authorities and social partners address local energy poverty through coordinated solutions, including contact points and focus groups with housing entities, to facilitate knowledge exchange on renovation programs and targeted solutions.

The evidence-based and collaborative approach will be implemented in three pilot municipalities in Central, Southern and Southeastern Europe: Piraeus (Greece), Rumia (Poland), and Torres Vedras (Portugal) and, while ensuring the scaling up of the LOCATEE framework to more municipalities and regions across Europe.

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7	Municipio De Torres Vedras	COTV	PT	
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Executive Summary

While energy poverty still looms large in the European Union, cooperation and coordinated efforts between different actors from the national to the local scale are key to drive effective transformation towards a just energy transition. Adequate detection at the regional and local level is a crucial step for local authorities to design impactful actions that address the needs of vulnerable households. This report aims to provide valuable insights for the municipalities of Piraeus (Greece), Rumia (Poland), and Torres Vedras (Portugal) to address energy poverty in private multi-apartment buildings within their territories, within the context of the LOCATEE project. It reviews 68 energy poverty assessment approaches published in recent scientific literature and selected grey literature from EU projects and initiatives on energy poverty to identify the datasets, indicators, and practices that can be leveraged to build a comprehensive and robust energy poverty assessment, combining administrative data at national and municipal levels. National statistics are the most used data source, and energy poverty is most frequently depicted as a problem of space heating over expenditure. Direct measurements estimating energy poverty levels and headcounts require income, expenditure and consensual indicators that are not easily available, requiring dedicated data collection at the household level. Building indicators are mostly used as indirect indicators of energy poverty, integrated in composite vulnerability analysis, as predictors of deprivation or as intermediate indicators for estimating energy expenditures. Unconventional indicators include health status, energy disconnections, other basic expenses (e.g. water, transport), energy literacy, building renovations, indoor air quality, outdoor space, and occurrence of extreme weather events.

This review produces inputs to the design of a toolkit that will integrate both diagnosis and solution assessment by identifying the most cost-effective solutions for the specific technical and economic conditions of the building and household. It also draws a set of general recommendations regarding energy poverty assessment, highlighting the need for tapping different data sources; developing comprehensive and inclusive assessments covering the multiple dimensions of the problem, combining objective and subjective indicators, and involving stakeholders in the co-design of the assessment; and addressing aspects related to building typology, renovation and energy efficiency improvement and summer energy poverty. These insights can be useful for other local governments in their energy poverty diagnoses and policy planning.

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Acronyms

CoM – Covenant of Mayors

EC – European Commission

EED - Energy Efficiency Directive

EU – European Union

EU-SILC - EU Statistics on Income and Living Conditions

EPAH – Energy Poverty Advisory Hub

HBS - Household Budget Survey

MAB - Multi-apartment building

MS – Member State

M/2 - low absolute energy expenditure

NECP - National Energy and Climate Plan

2M - high share of energy expenditure in income

1 Introduction

Energy poverty refers to the inability of a household to access the energy services necessary for a decent standard of living and health. The European Commission in the recast of Energy Efficiency Directive (EED) defines it as *"a household's lack of access to essential energy services that provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lightning, and energy to power appliances, in the relevant national context, existing social policy and other relevant policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes"* (Directive (EU) 2023/1791). This EU-wide definition was a critical step toward harmonising national approaches and enabling comparable, coordinated policy responses across Member States (MSs).

The drivers of energy poverty are multidimensional and context dependent. At their core, they include:

1. Low household income
2. High energy prices
3. Poor energy efficiency of buildings and appliances

(Gouveia et al., 2022; ComAct, 2023).

Bouzarovski and Petrova (2015) proposed a broader framework, identifying six driving factors of energy vulnerability: access, affordability, flexibility, energy efficiency, needs, and practices, for a more comprehensive picture of the circumstances that create this multidimensional problem.

The structural and economic factors are often compounded by personal characteristics, such as gender, age, health, socioeconomic status, or household composition; contextual conditions, including climate zone or access to fuel; and broader socio-political factors, including weak social protection systems and underregulated energy markets (ComAct, 2021).

The effects of energy poverty are extensive, affecting physical and mental health, social inclusion, and economic resilience. Energy-poor households may face exposure to cold or overheating, respiratory illnesses, cognitive impairment, and even premature mortality in extreme cases (Gouveia et al., 2022). Children in such households are especially vulnerable, often experiencing lower educational attainment and reduced social and emotional well-being compared to their peers (Gouveia et al., 2022; Cornelis, 2025).

Energy poverty is typically defined at the household level, which is helpful for understanding who is affected. However, this definition and perspective can limit the effectiveness of policy and intervention measures in certain contexts, particularly in multi-apartment buildings (MABs). In such settings, energy efficiency upgrades – the most effective long-term solution to energy poverty – cannot always be implemented by individual households alone but require action at the building level (*e.g.*, through external insulation).

In Central and Eastern Europe, as well as in parts of Southern Europe, many low-income households reside in privately owned multi-apartment buildings. These buildings, typically defined as structures with three or more residential units, present a unique set of challenges. Ownership of apartments in these buildings is fragmented among multiple households, and buildings often have a mixed socio-economic profile. Even more, in CEE countries, many MABs were built during the socialist era and now suffer from severe technical deterioration.

Because of this, energy renovations in MABs require coordinated, building-wide action, which is frequently hindered by low residents' engagement, absentee owners, and distrust among residents. Inadequate legislation and poor building-level governance and decision-making are also important constraints. Even if only a few households within a building are vulnerable to energy poverty, the entire building may still be considered "energy poor" due to financial, technical, or organisational barriers that prevent necessary renovations.

Effective measurement of energy poverty is essential for identifying vulnerable households and buildings, designing targeted support measures, and monitoring the success of interventions. For municipalities and local actors, reliable data is the foundation for prioritising renovation efforts, allocating resources, and ensuring no community is left behind. Standard household-level indicators, however, may not capture the full picture in multi-apartment contexts, where structural and community-level barriers are equally decisive.

To address this type of situation, the ComAct project[1], for example, introduced the concept of building-level energy poverty, expanding the traditional household-level view to more adequately reflect these collective vulnerabilities. As defined by ComAct, "*Building-level energy poverty refers to the very particular situation where the financial, technical, and community conditions in a building create a situation of high and inefficient energy consumption for the units, without the possibility of intervention under the existing mainstream subsidy schemes*" (ComAct, 2023).

Herein, in this deliverable (D3.1 of task 3), we lay the groundwork for the LOCATEE toolkit by reviewing and selecting energy poverty indicators suitable for local-level application, particularly in the context of private multi-apartment buildings. It conducts a review of energy poverty assessment approaches published in scientific literature, aiming to identify the datasets, indicators, and practices that can be leveraged by local governments to conduct a comprehensive and effective diagnosis. It seeks to inform the development of LOCATEE actionable diagnostic tool that will enable municipalities to identify energy-poor areas, buildings, prioritize interventions, and design effective renovation strategies.

This review aims to investigate the following research questions:

▪ *What indicators can be used at the building/local scale to assess energy poverty?*

▪ *Which administrative datasets and sources can be tapped for that purpose?*

[1] https://cordis.europa.eu/project/id/892054

- *What are the main takeaways in the current local-scale energy poverty measurement?*

2 Overview of Energy Poverty Measurement in the EU

Indicators allow us to quantify socioeconomic phenomena such as energy poverty. In fact, the objective of indicators is to provide a numerical value to different aspects of one phenomenon, quantifying the latter and thus allowing for comparisons of the same phenomenon under different circumstances (*e.g.*, energy poverty across different countries). When it comes to energy poverty, there is no single indicator for it. Rather, different indicators quantify different nuances of the issue, bringing additional and complementary perspectives. Thus, a combination of energy poverty indicators should always be employed.

Energy poverty is typically measured using three main approaches: subjective (or consensual) indicators, such as self-reported inability to keep the home warm; expenditure-based indicators, which assess the share of income spent on energy; and composite indicators, which combine multiple variables to reflect multidimensional deprivation (Thomson et al., 2017; Tirado-Herrero, 2017; Turai et al., 2021; Szemző and Gerőházi, 2024).

Each of these has limitations, particularly in multi-apartment settings. Subjective measures can reflect perception bias, and expenditure indicators may underestimate underconsumption or reliance on informal fuels (e.g. self-collected firewood). Furthermore, most national-level data collection is not granular enough to support municipal-, neighbourhood- or building-scale diagnosis, a gap that this project aims to address.

The recast of the Energy Efficiency Directive (Directive EU 2023/1971), in its Article 8.3, states that Member States shall establish and achieve a share of the required amount of cumulative energy savings among people affected by energy poverty or vulnerable groups, considering four main indicators of energy poverty. These are:

- the inability to keep the home adequately warm;
- the arrears on utility bills;
- the total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor;
- the at-risk-of-poverty rate.

All these indicators can be found in the Eurostat repository, specifically in the EU Statistics on Income and Living Conditions (EU SILC). All these indicators should be included in the National Energy and Climate Plans (NECPs), with updates present every two years.

On its 2020/1563 recommendation on energy poverty, the European Commission provided "indicative guidance on adequate indicators for measuring this issue. It proposes a set of indicators deriving from harmonised EU data to monitor energy poverty at the EU level and identify national differences, stating that these can be complemented by indicators stemming from each national context. Besides the ones already identified in the EED, it proposes the composite indicators "share of population at risk of poverty (below 60% of national median equivalised disposable income) not able to keep their home adequately warm; "arrears on utility bills: share of population at risk of poverty (below 60% of national median equivalised disposable income) having arrears on utility bills", intersecting two different indicators. It also identifies expenditure on electricity, gas and other fuels as a proportion of total household expenditure; proportion of households whose share of energy expenditure in income is more than twice the national median share; and share of households whose absolute energy expenditure is below half the national median are main indicators to assess energy poverty. As complementary indicators, in addition to "share of population at risk of poverty" and "share of population with leak, damp or rot in their dwelling", the recommendation identifies electricity prices, gas prices, and final energy consumption as complementary indicators.

The Energy Poverty Advisory Hub has created an indicator dashboard (EPAH, 2025), compiling 28 indicators that can be used to assess different aspects related to energy poverty incidence, addressing several macro-areas, including climate, facilities and housing, mobility, and socioeconomic factors, encompassing all the indicators mentioned previously. It includes two expenditure-based indicators stemming from the previous Energy Poverty Observatory - the high share of energy expenditure in income (2M), and the low absolute energy expenditure (M/2), which have been frequently used for identifying households in energy poverty. These indicators are computed using national Household Budget Surveys (HBSs) data and consider households paying twice the median of energy expenditure in income or half of the median, representing situations of high energy expenditure shares or situations of underspending to meet economic ends. The consensual indicators "inability to keep home adequately warm" and "arrears on utility bills, collected annually for all EU member states are displayed in Figure 1. The two aforementioned expenditure-based indicators are presented in Figure 2.

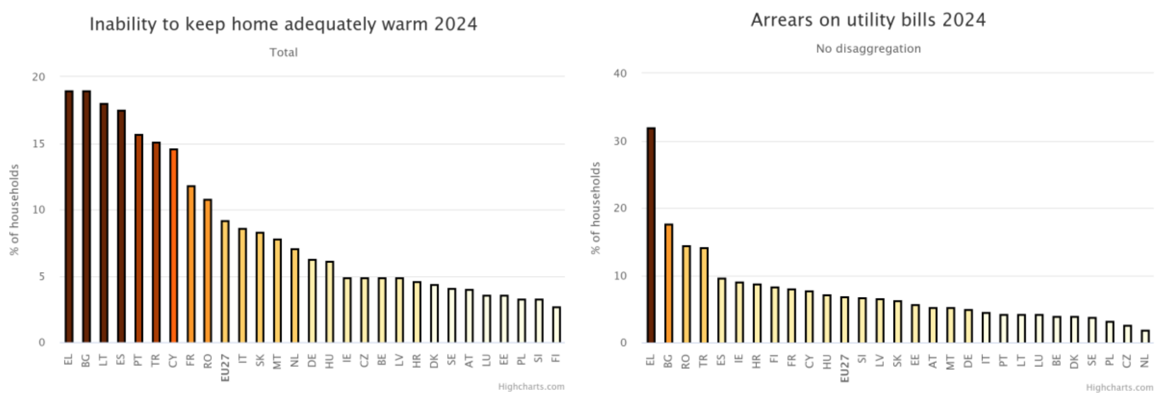


Figure 1 - The indicators "Inability to keep home adequately warm" and "Arrears on utility bills" for every Member-State in 2024 (EPAH, 2025)

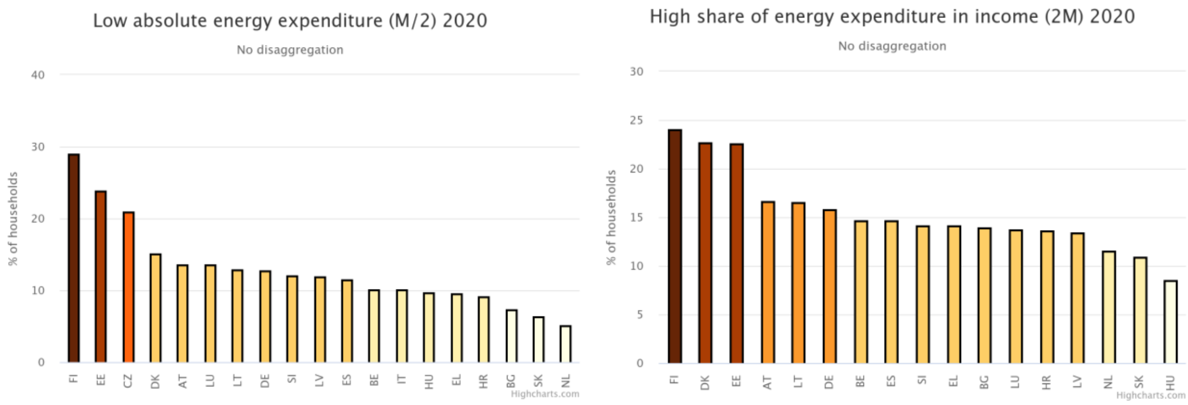


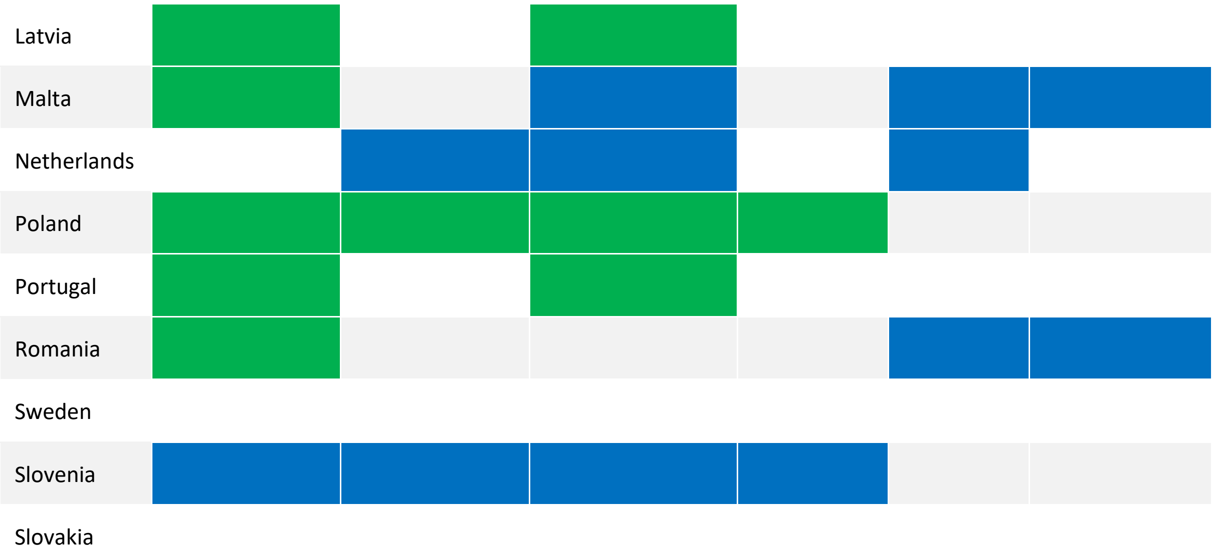
Figure 2 - The M/2 (left) and 2M indicators for every Member State in 2020 (EPAH, 2025)

In addition to the energy poverty indicators available at the European level, previously discussed, several national indicators are also available, either depicted in national energy poverty strategies (*e.g.,* as in Portugal) or in their National Energy and Climate Plans (European Commission *et al*., 2024). In Belgium, indicators include households with energy bills that represent a high share of their income (measured energy poverty); households that minimise energy consumption to meet financial constraints (hidden energy poverty); and households that self-report inadequate heating (subjective energy poverty). In Greece, indicators include households meeting specific criteria related to energy consumption costs and income levels. In France, indicators include households where energy expenditure exceeds a certain percentage of income (energy effort rate); self-restriction phenomena not captured by economic indicators (indicator on the feeling of cold); and a weather-corrected indicator. In Croatia, risk indicators are present, including household income, building energy rating, and total energy costs as a percentage of income. In Ireland, indicators include households spending more than 10% of income on energy; and metrics related to electricity and gas customer arrears in annual bills. In Italy, indicators include energy expenditure relative to heating needs, and indicators related to low income combined with high energy costs and arrears on utility bills. In Lithuania, indicators include the share of households with significant energy expenditure and metrics related to heating affordability and household maintenance costs. In Luxembourg, combined indicators *High Energy Effort Rate* (TEE) and *Low Income, High Cost* (BRDE) address energy waste and household maintenance costs. In the Netherlands, metrics are present assessing the combination of low income with high energy bills or low-quality housing. Finally, in Poland, indicators are present which weigh the energy bills in the household budget; the number of beneficiaries of the Social Energy Tariff; and the inability to keep dwellings cool in summer. (European Commission et al., 2024)

As of June 2025, 24 out of 27 MSs have submitted their final updated NECPs, several months past the deadline, with the NECPs of Belgium, Estonia, and Poland still missing. Compared to the latest NECP update available (2023), four more countries, namely Czechia, Hungary, Portugal, and the Netherlands, introduced an official energy poverty definition, in addition to the other 15 countries which already had. When it comes to indicators, five more countries, namely Croatia, Denmark, Hungary, Romania, and Slovenia, reported indicators, in addition to the other 18 which already had. It is worth noting that Croatia and Romania have added indicators that were not previously considered in the NECP. These are added in blue in Table 1. Lastly, several EU countries present energy poverty observatories and/or relevant action plans. These are namely: Austria, Belgium, Croatia, France, Greece, Italy, Portugal, Spain, Romania. It must be noted that for Belgium, this is not an official one, but rather from the King Baudouin Foundation, whereas for Croatia, a plan to introduce a observatory was mentioned in the latest update of the NECP (Livraghi and Broc, 2025).

Table 1 - Overview of main energy poverty indicators, or their reported equivalent, across MSs – in green when information was available from the 2023 NECP draft, in blue when it was added in the last submitted NECP (European Commission et al., 2024)

Member State	Inability to keep home adequately warm (ilc_mdes01)	Arrears on utility bills (ilc_mdes07)	Total population living in dwellings in bad condition (ilc_mdho01)	At risk of poverty rate (ilc_li02)	High share of energy expenditure in income (2M)	Low absolute energy expenditure (M/2)
Austria						
Belgium						
Bulgaria						
Cyprus						
Czechia						
Germany						
Denmark						
Estonia						
Greece						
Spain						
Finland						
France						
Croatia						
Hungary						
Ireland						
Italy						
Lithuania						
Luxembourg						



While progress has been observed in energy poverty policymaking at the national level, at the regional and local levels, efforts for mitigating energy poverty are still scarce and diffuse. In line with ameliorating such efforts, the Covenant of Mayors drafted reporting guidelines for energy poverty; thanks to the Baseline Emission Inventory & Risk Assessment, before defining indicators, municipalities can perform a comprehensive assessment of their energy (poverty) needs. Only then can municipalities proceed to select from over 20 indicators across five macro-areas: climate, housing, mobility, socioeconomic aspects, and participation, with options to track progress by marking "current level" and setting a "target level" for future monitoring (CoM, 2025).

The European Commission emphasises the need for cooperation between relevant actors and coordinated efforts at the regional and local levels to complement national-level analysis with bottom-up approaches (EC, 2020). In its 2023 recommendation (2023/2407), the Commission urges Member States to "ensure an enhanced governance with a holistic approach to tackle energy poverty, including cross-departmental and vertical collaboration across national, regional, and local governance structures, involving closer engagement with vulnerable households and relevant energy and social partners and stakeholders." Appropriate regional and local level detection is key as regional and local authorities play an important role in identifying the key financial and social challenges for energy-poor households and implementing effective and impactful actions to drive a fair, inclusive, and sustainable energy transition.

3 Review Methodology

This report conducts a structured literature review, which follows an analogous process to a systematic review but with a lesser degree of exhaustiveness and formality of protocol, leading to a more flexible and exploratory approach. Also described as rapid reviews, they synthesise evidence, streamlining certain systematic review methods to provide and describe available evidence and contextual information in a resource-efficient manner, thereby supporting decision-making and potentially identifying the direction of evidence and its strength. However, they do not intend to formally synthesise evidence into normative conclusions (Vilar, 2022; Garrity *et al*., 2024). It aims to synthesise reliable scientific evidence for policymakers within a field where literature has considerably increased in recent years, and approaches are diverse and often substantially diverse.

This approach specifically emulates the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework (Page *et al*., 2021) to capture the relevant studies in the field of energy poverty measurement research. PRISMA provides "guidance for the reporting of systematic reviews evaluating the effects of interventions" (PRISMA, 2025). Specifically, this review aims to assess the data indicators and methods employed for identifying or characterising the energy-poor population and evaluating this multidimensional issue, with a particular focus on higher granularity case studies (household, building, and neighbourhood levels) and multi-apartment buildings. The review also aims to capture not only diagnostic studies but also studies oriented towards mitigation interventions, namely, retrofits or direct financial support.

The review approach focused on several aspects to analyse the articles, such as unit of analysis, spatial scale, season, goal of the study, method, target groups, origin, type and source of the data, and type of indicators, building on the work of Palma et al. (2024). The type of energy poverty, regarding the expression of the problem within the household, which can take the forms of over expenditure for energy services, under expenditure, perceived inability, vulnerability level or restriction of other basic needs. Ultimately, the goal is to collect potential best practices in energy poverty measurement at this level, that can inform the design of a tool to match tailored interventions to specific groups of households, seeking to increase its impact in mitigating energy poverty.

This review used the Web of Science Core Collection[2] database to search for peer-reviewed research papers on the subject. Web of Science features a diverse collection of published scientific literature spanning various areas of study. It is worth noting that energy poverty is often referred to as fuel poverty, as the terms can be used interchangeably, although they may also have slightly different connotations. Historically, energy poverty has often been described as a household's lack of access to energy in developing countries. On the other hand, the term "fuel poverty" has been primarily used to describe the inability to afford adequate

[2] https://www.webofscience.com/wos/woscc/basic-search

warmth (Li *et al*., 2014), particularly in developed countries, stemming from early research and policy in the UK and Ireland. This study focuses on a European definition of energy poverty, closely linked to affordability. However, both terms were included in the search to avoid excluding papers that focus on the intended definition of the problem. Thus, both “energy poverty” and “fuel poverty” were included as keywords in the search, together with a group of other keywords, aiming to capture the different aspects of interest. The following string of keywords were used in the search: ("energy poverty" OR "fuel poverty") AND ("flat" OR “flats” OR “apartment” OR “apartments” OR “apartment building” OR “household level” OR “building level” OR "neighbourhood level" OR "district level"). A total of 181 studies were found in this initial search. These keywords were searched in all searchable fields of the articles, including title, keywords, and abstract.

The screening process consisted of several stages. Firstly, only peer-reviewed studies were included. All non-English written studies were excluded from the sample. Moreover, only case studies focusing on European countries were included, as the goal is to look into local energy poverty assessment in the context of European countries. Subsequently, the title and abstract were analysed, aiming to exclude studies that did not fit the criteria of interest. Finally, a first content analysis was conducted to identify the final pool of studies to be reviewed, resulting in a total of 50. In the final step, scientific articles known to the authors, originating from their national contexts and meeting the inclusion criteria, but not identified in the search process, were also included, resulting in an additional 20 articles being added to the final sample. The screening process is displayed in Figure 3.

This article review was finally complemented by a complementary grey literature analysis of selected technical reports, surveys, and tools. The Covenant of Mayors Europe reporting guidelines on energy poverty (CoM, 2025) propose a set of indicators to guide signatory municipalities in their energy poverty assessment and monitoring approaches, which were reviewed in this report. The EU projects Reverter (Reverter, 2025), PowerPooR (Powerpoor, 2025), EmpowerMed (2025), and Renoverty (Renoverty, 2025) were also analysed, aiming to find indicators used to identify energy-poor households in their surveys, tools and publications. Selected projects from the C40 network (Morel et al., 2022) were also investigated for potential innovative use of indicators underlining energy poverty.

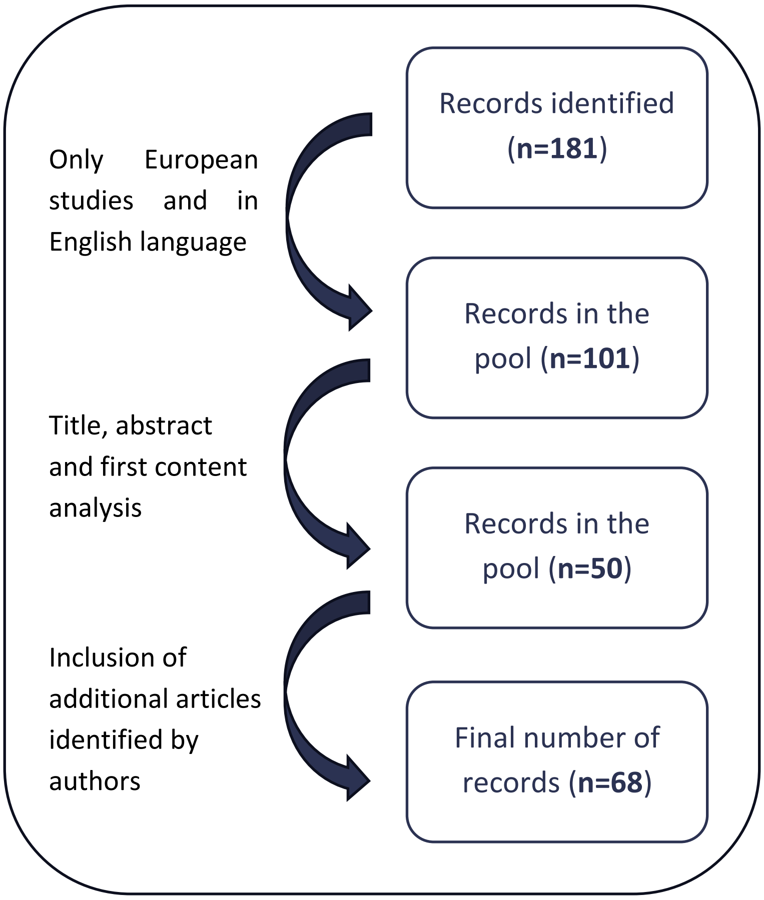


Figure 3 - Publications screening process diagram

4 Review of Energy Poverty Indicators – Results and Discussion

4.1 Descriptive Analysis

Before delving into the specifics of data and indicators used in the different studies, it is useful to conduct a brief descriptive analysis of the review pool of articles. The list of articles reviewed can be consulted in Table A1 in the Appendix. Considering the geographical context (Figure 4), studies encompass a wide range of countries and regions. However, the majority focus on southern European countries (Portugal, Spain, Greece, and Italy), as well as Poland and the United Kingdom. The higher number of studies in Portugal, Greece, and Poland is justified not only by the considerable rise in the body of energy poverty literature in these countries but also by the additional inclusion of papers known to the authors, who are particularly knowledgeable about the work conducted in their countries on this subject. These assumptions take on special relevance as they may provide direct input regarding indicator and data availability to the LOCATEE project, which focuses on regions in these three countries. Other countries, such as Spain and Italy, also have a significant body of work in this topic, potentially due to the high levels of energy poverty in their populations, which drives the need for more knowledge and study of this issue. The large number of studies from the UK is also logical, considering it is where the concept was first coined and investigated, and the fact that leading research works and a comprehensive body of literature have emerged from the country.

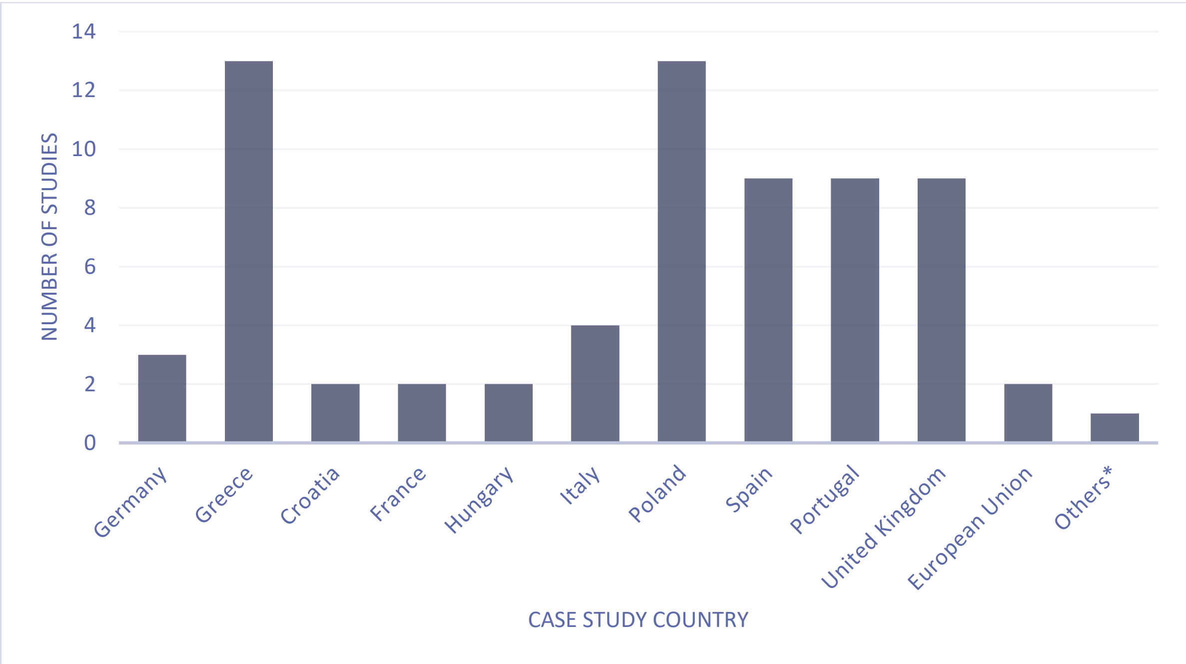


Figure 4 - Number of studies per country

*Others: Bulgaria, North Macedonia, Lithuania, Netherlands, Ireland, Czechia, Switzerland, Slovenia, Serbia, Norway, Ukraine

Regarding the publication date (Figure 5), it represents a recent pool of studies, with most having been published within the last 6 years. This is favourable for the purpose of the study, as it guarantees the actuality and timeliness of the developed methods, depicting the current state of the art, as well as the data sources used, which can serve as a reference and inspiration for the LOCATEE project.

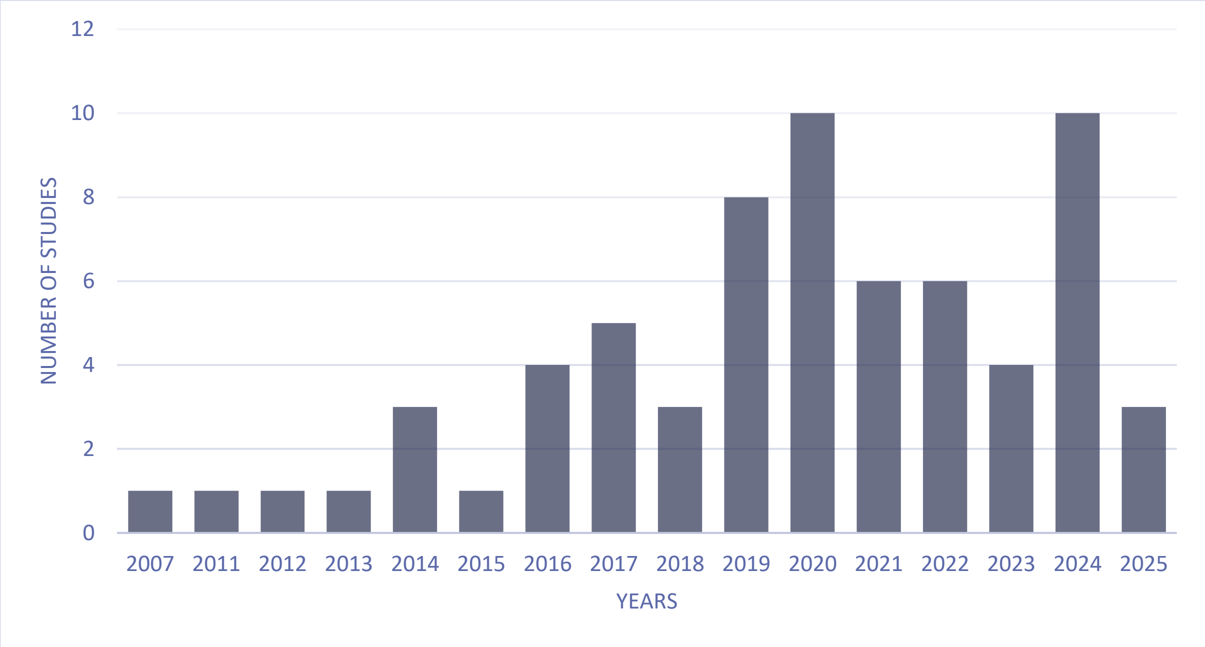


Figure 5 - Number of studies per year of publication

Most studies use the household, dwelling, or building as the unit of analysis, as intended in the review's design, since the purpose of this review is precisely to develop a toolkit that works with this unit, linking energy poverty assessment with energy retrofit interventions. However, the search process also included studies that use regions and areas as the unit of analysis, using average values to characterize energy poverty indicators. On the other hand, most studies are geographically and contextually specific, focusing on a particular region, municipality, district, or even just the building unit. This is likely due to data access, which is often limited in its range and quantity, and is often only suitable for specific case studies. On the upside, these studies uncover relevant data sets and sources at the local level, which might otherwise remain untapped. Some other authors access data that enables country-wide analysis, whether at the national level or for regionally disaggregated data for every region of the country, allowing for insightful comparative analysis. The number of studies per unit of analysis and spatial disaggregation are displayed in Figure 6.

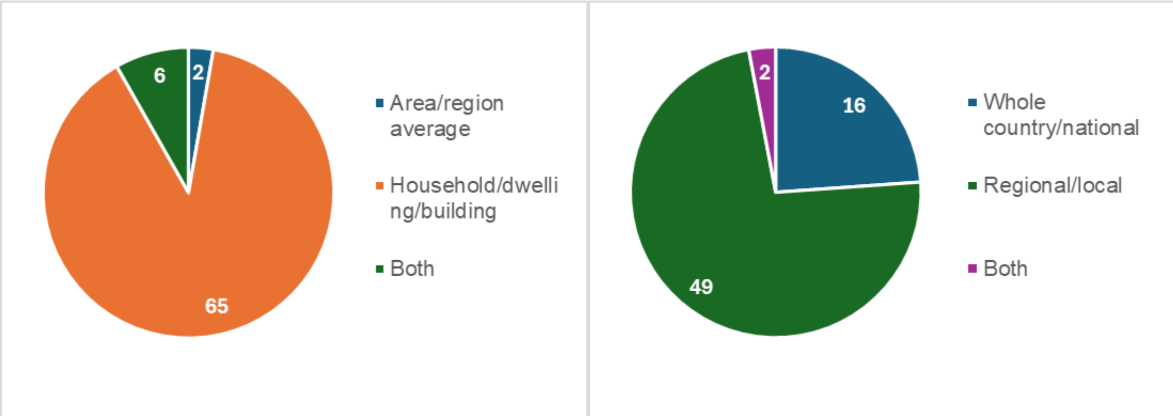


Figure 6 - Number of studies per unit of analysis (left) and spatial disaggregation

Indoor space heating remains the most widely addressed type of energy service, and winter is the primary focus of most studies (49) (Figure 7). Heating has historically been the focus of most energy and fuel poverty studies, whereas summer energy poverty is still arguably underexplored. It is addressed individually in 30 studies, which investigate both winter and summer energy poverty ("both" in Figure 7). Indoor cooling and summer vulnerability are an increasing social struggle for the European population (Thomson *et al*., 2019). Some studies considered total energy consumption or expenditure in their approach ("joint" in Figure 7), thus not differentiating between different energy services in the analysis. It provides a more comprehensive depiction of energy vulnerability, although it does not enable ascertaining whether the vulnerability is associated with the provision of a particular energy service.

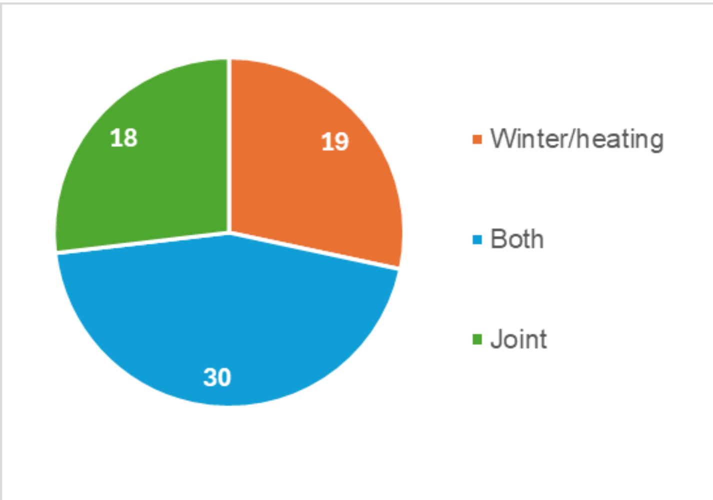


Figure 7 - Number of studies per season focus

Each study aims to investigate energy poverty by capturing one or more of its expressions or manifestations, or even its specific drivers and causes. We divide the studies by the following types of analysis: abnormally high energy consumption or expenditure, which is considered an indicator of considerable burden in the household budget; abnormally low energy consumption or expenditure, a sign of self-restrictive energy consumption behaviour; self-reported inabilities, which related to perceived difficulty or inability to access adequate levels of energy services; and alternative indicators, which can be used individually or combined into a multidimensional index to depict energy poverty vulnerability through its causes and drivers. In the reviewed pool, most studies (#33) investigate and interpret energy poverty as an over-expenditure problem, developing quantitative analyses which follow the predominant theoretical tradition in this field. Most of these studies measure incidence, which means they quantify the number of people or households experiencing energy poverty. An already significant number of studies address this issue from another perspective while still using similar data (#15), understanding it as also a problem of underconsumption ("hidden energy poverty" as described by Meyer *et al*., 2018). Other authors (#18) use qualitative self-reports of the households' lived experience to assess energy poverty levels, which is also a popular approach. Despite their higher subjectivity, these indicators are intelligible and stem from a more participatory bottom-up approach (Thomson *et al*., 2017). Assessing more than one of the described metrics can enhance the assessment, thereby increasing comprehensiveness in identifying different energy poverty profiles (Palma *et al*., 2024). Menyhért (2024) highlights that a diversity of backgrounds and conditions creates energy poverty, and self-reported and expenditure-based indicators identify different population segments, including one that suffers from compound energy deprivation. From the revised pool, only eight of the #67 studies developed two or more of these methods together. A shorter sample of studies uses proxy indicators to measure vulnerability levels, relying on supporting or indirect indicators instead of more direct measurements of incidence. For example, the building age or conservation state can be a proxy of energy efficiency, and the household employment status can be a proxy of economic conditions or purchasing power. Proxy indicators often capture different aspects related to relevant causes, drivers, and effects of energy poverty, but are not fit to directly capture it. These indicators are important tools for addressing the lack of data that hinders the use of direct indicators (Sanchez *et al*., 2020), a common issue in local assessments. In less frequent approaches, authors can also combine vulnerability approaches with more direct assessments (Horta *et al*., 2019).

Most studies rely on secondary data, collected by other entities. National statistics authorities are the primary data source for the indicators used in these studies, which are collected through censuses, national surveys, or other databases. However, a significant number of authors have already developed their analysis using their own data, collected through surveys, questionnaires, or field measurements. Whereas secondary data are often more easily available and in greater quantity and diversity, primary data enables more tailored analysis, allowing for the depiction and assessment of specific forms and nuances of vulnerability, such as those affecting underprivileged communities, which are often overlooked by existing statistics (Ruiz-Rivas *et al*., 2023). The number of studies per type of energy poverty and origin of data can be consulted in Figure 8.

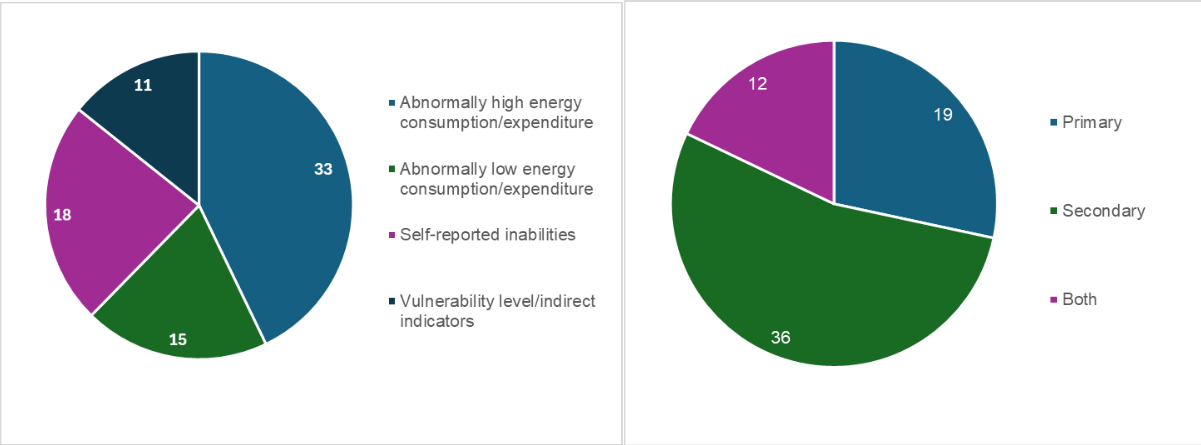


Figure 8 - Number of studies per type of energy poverty (left) and per origin of data (right)

4.2 Indicator and Data Analysis

Each approach utilises different indicators and data to portray relevant aspects of this issue, whether they represent causes, drivers, effects, or other indirect determinants. In this review, the data and indicators have been categorised according to the main dimension in which these aspects are integrated, in a manner similar to the EPAH indicators reports (Gouveia et al., 2022; Gouveia et al., 2023) and dashboard (EPAH, 2025). The different dimensions are the following:

- Buildings (*e.g.,* infrastructure and energy equipment);
- Energy (*e.g.,* demand, consumption, expenditures);
- Economic (*e.g.,* income, energy prices);
- Climate (*e.g.,* temperature, heating and cooling degree days);
- Sociodemographic and Vulnerable Groups (*e.g.,* age, educational level);
- Other Indicators (*e.g.,* health, thermal comfort, indoor air quality).

Although every indicator and dataset are examined, particular attention is put on administrative data at different levels, as it is more likely to be available in the context of the project. Special focus is also given to apartment buildings and apartment typologies, since these constitute the unit of analysis and intervention within the project.

4.2.1 Buildings

The Building dimension is key to this study because one of the main purposes of the future LOCATEE toolkit is precisely to link energy poverty measurement to energy efficiency upgrades on the building envelope or its energy systems. Poor building energy efficiency, including Heating, Ventilation, and Air-Conditioning (HVAC) systems, is considered one of the primary causes of energy poverty (Dobbins *et al.*, 2019), thus playing a crucial role in mitigation efforts. All the building indicators are displayed in Table 2. For most analysed studies, the building dimension is often integrated as an indirect indicator or proxy of energy poverty, such as energy performance or energy efficiency, mostly used to characterise potential vulnerability to energy poverty instead of estimating the number of people suffering from this condition.

The review protocol was designed to address building typologies and multi-apartment buildings and apartments in particular, which are the main target of the project, hence it is probably the most comprehensive building indicator. The aspect of building type is integrated into the studies as the only typology being addressed in the case-study area or housing block, or statistical approaches, as an independent variable or predictor of energy poverty. Other studies define building or dwelling typologies to characterise the building stock that they aim to analyse. The building type is particularly relevant, as it is an important determinant of energy performance and energy demand, but it also links to other socioeconomics factors that play an important role in shaping energy poverty. This indicator can be obtained in multiple datasets, from public national statistics and surveys to online platforms, surveys microdata, and energy scheme programs, which can be more challenging to access. Despite LOCATEE's focus on private multi-apartment buildings, studies focusing on social housing dwellings were also included in this review, as these dwellings are mostly of the apartment typology, and relevant indicators and datasets can be identified.

The state of conservation of the building or dwelling is also depicted in several studies. Households living in a dwelling with damp, mould or rot in its elements indicator is commonly used, available in the EU SILC (Karpinska and Smiech, 2020a), but also collected in an analogous form in dedicated surveys (*e.g.*, Boemi *et al*., 2017). It represents both an effect and a cause of energy poverty, as the precarious condition of the dwelling can lead to higher energy needs, but poor thermal indoor conditions can also contribute to the deterioration of building elements. More qualitative assessments of building quality, state of conservation, or maintenance condition are also used in some approaches (Boemi and Papadopoulos, 2019; Gouveia *et al*., 2019; Sánchez *et al.,* 2020; Clavijo-Núñez *et al*., 2024).

The building or dwelling age or year of construction is also a thoroughly used indicator (e.g. Walker *et al*., 2014; Little *et al.,* 2024; Sánchez *et al*., 2020), serving as a useful proxy indicator of energy performance, as well as dwelling constructive characteristics and parameters. It is widely available in public national statistics, including at the regional and local levels. It can also be obtained in municipal registries such as building cadasters and other data sources. Using national or European thermal regulations, it is possible to establish a link between the building's age and a set of constructive and thermal parameters (*e.g.,* Gouveia *et al*., 2019), which can enable further analysis, for instance regarding energy demand modelling. These can also help facing the lack of more granular data.

The type of energy system used for the different energy uses is an indicator frequently collected, as well. It is often considered in a dichotomous form, as existence or absence in the dwelling, the latter representing an indicator of increased vulnerability. However, it also provides relevant information regarding the dwelling's energy efficiency and the household's energy access. The Covenant of Mayors (CoM, 2025) identifies households with only oil boilers, wood calefactions, or conventional gas boilers as potentially more vulnerable and households relying primarily on clean fuels and technology as in a more favourable position in terms of their energy provision. This specific form of deprivation can be found in Poland, where coal stoves are still commonly used, even in multi-family buildings. Data is collected by one specific registry, the Central Register of Emissions of Buildings.

The building or dwelling constructive characteristics are also used frequently in the process of defining building typologies or as proxies of energy performance and efficiency. They are also used in physical models to directly estimate buildings' energy needs and potential energy consumption. Building elements (floor, walls, roof, windows, façade, structure, glazing), geometric characteristics, type of construction and materials, shading, are examples that can be used in an ensemble but that can also provide specific insights into energy transfer within dwellings. These data are often available in public national statistics. Dwelling size is related to energy needs and can also be used to investigate home overcrowding. The indicator "number of rooms" is easily accessible proxy indicator for dwelling size, available in national statistics (Karpinska *et al.*, 2021; Panão, 2021; Strmota and Ivanda, 2021).

As a subsequent step, a smaller number of authors link the different constructive characteristics to their thermal characteristics, with similar purposes – to characterise thermal performance of buildings in connection to energy poverty vulnerability. Heat transfer coefficients (U-values), thermal resistance, energy performance factors, and ventilation variables (*e.g.* air changes) are some of the parameters included in these studies. Although not so easily accessible, data on these thermal features can be found in national regulations, reference building construction documents, or energy performance certificates, whose accessibility varies from country to country. These parameters can provide valuable information about the energy efficiency of the building, as well as serving as reference parameters of typical buildings (or typologies), which can be used when there is no information on these parameters for the housing stock of a particular area.

An important variable often overlooked is the building renovation, which can be captured in several ways. Only three authors integrate this aspect (Aranda *et al.*, 2018; Guilbert, 2024; Stegnar, 2025). Number of retrofits, renovation status and change in thermal parameters after renovation are specific examples of this aspect that can be integrated, providing a more detailed and timely depiction of building condition and thermal performance. Clavijo-Núñez *et al.* (2024) propose a unique indicator – building accessibility, which introduces an important aspect when considering whole building function, particularly relevant for people with physical disabilities. It can be connected to renovation works conducted in the building. However, this variable requires systematic work and monitoring of the building condition at the municipal level, which is often not the case, especially if renovations concern private buildings.

Table 2 - Building indicators per data source and study reference

Indicator	Data Source	Reference
Building type (house or apartment)	EU-SILC; Household Budget Survey; ODYSEE-MURE; primary surveys; TABULA online tool; UKHLS, National Energy-efficiency Data (NEED)(UK); AWP scheme (public) survey (UK); Energy Saving trust (private) (UK); Census (Spain); British Household Panel Survey; household-level microdata database of Statistics Netherlands; DesignBuilder software;	Walker *et al*. (2014); Roberts *et al.* (2015); Lis *et al.* (2016); Boemi *et al.* (2017); Gouveia *et al.* (2018); Karpinska and Smiech (2020a); Spiliotis *et al.* (2020); Grdenic *et al.* (2020); Boemi *et al.* (2020); Karpinska and Smiech (2020b); Sánchez *et al.* (2020); Panão (2021); Karpinska and Smiech (2021); Lyra, *et al.* (2022); de la Paz *et al.* (2022); Vurro *et al.* (2022); Mulder *et al.* (2023); Spandagos *et al.* (2023); Rasanga *et al.* (2024); Little *et al.* (2024); Guilbert (2024); Arsenopoulos *et al.* (2025).
Age of building/dwelling	Household Budget Survey; Housing Energy Efficiency Agency; EU project (ENABLE); primary surveys; TABULA online webtool; AWP scheme (public) survey (UK); Energy Saving trust (private); EU-SILC; National Statistics and Census (Greece, Spain and Portugal); Survey microdata (Netherlands); Geodetic Administration of the Republic of Slovenia (GURS); Public datasets from the Slovenian Eco Fund; Energy performance certificates	Katsoulakos (2011); Walker *et al.* (2014); Paravantis and Santamouris (2014); Lis *et al.* (2016); Simões *et al.* (2016); Gouveia *et al.* (2018) Gouveia et al. (2019); Papada and Kaliampakos (2019); Ntaintasis *et al* (2019); Horta *et al.* (2019); Gupta and Greg (2020); Boemi *et al.* (2020); Sánchez *et al.* (2020); Grdenic *et al.* (2020); Karpinska *et al.* (2021); van Hove *et al*. (2022); de la Paz *et al.* (2022); Mulder *et al.* (2023); Kazukauskas and Li (2024); Arsenopoulos *et al.* (2025); Little *et al.* (2024); Clavijo-Núñez *et al.* (2024); Stegnar (2025).
Conservation state (leaks/damp/rot; building quality)	EU-SILC; primary surveys	Boemi *et al.* (2017); Sokolowski *et al.* (2020); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Karpinska and Smiech (2021); Sokolowski *et al.* (2023); Szczygiel *et al.* (2024); Aristondo *et al.* (2024)
Type of energy system	Household Budget Surveys; Eurostat, Statistical Authorities (Greece); primary surveys; AWP scheme (public) survey (UK); National Statistics and Census (Spain, Portugal); companies managing social housing (Spain); Tabula/Episcope; local authorities surveys;	Katsoulakos (2011); Terés-Zubiaga *et al.* (2013); Walker *et al.* (2014), Gouveia and Seixas (2016); Lis *et al.* (2016); Boemi and Papadopoulos (2017); López-Bueno *et al.* (2018); Papada *et al.* (2018); Gouveia *et al.* (2018); Aranda *et al.* (2018); Ntaintasis *et al.* (2019); Grdenic *et al.* (2020); Boemi *et al.* (2020); Gupta and Greg (2020); Sánchez *et al.* (2020); Panão (2021); Clavijo-Núñez *et al.* (2024);
Building/dwelling characteristics (e.g. size, areas, height, bearing structure, materials,	Household Energy Use Surveys; Household Budget Surveys; Virtual Survey Method (VSM), Remote Cataloguing, Measurement and Mapping method (RCMM), Google Street View and Google Earth; Sensors	Tirado-Herrero and Ürge-Vorsatz (2012); Karpinska *et al.* (2021); Lis *et al.* (2016); Pittam and O'Sullivan (2017); Ramos *et al.* (2017); Szulgowska-Zgrzywa *et al.* (2023); Szulgowska-Zgrzywa *et al*. (2022); Papada *et al.* (2018); Teli *et al.* (2016); van Hove *et al.* (2022); Mayer *et al.* (2014); Arsenopoulos *et al.* (2025); Boemi *et al.*

insulation, shading, window type)	(in-situ measurements); Statistical Authorities; primary surveys and questionnaires; Enable-EU project; AWP scheme (public) survey (UK); RdSAP reference tables (UK); Housing Census; Statistics Netherlands; municipal companies; ISO 6946; Civil Engineering National Laboratory (Portugal); public company managing social houses; DesignBuilder V4.7; Geodetic Administration of the Republic of Slovenia (GURS); Public datasets from the Slovenian Eco Fund; local survey; Energy performance certificates;	(2017); Strmota and Ivanda (2021); Walker *et al.* (2014); Little *et al*. (2024); Sánchez et al. (2020); Mulder *et al*. (2023); Aranda et al. (2017); Terés-Zubiaga *et al*. (2013); Simões et al (2016); Gouveia and Seixas (2016); Gouveia *et al.* (2018); Aranda *et al.* (2018); Papada and Kaliampakos (2019); Gouveia *et al.* (2019); Ntaintasis *et al.* (2019); Horta *et al*. (2019); Gupta and Greg (2020); Spiliotis *et al*. (2020); Boemi *et al*. (2020); Antepara *et al.* (2020); Panão (2021); Sokolowski *et al.* (2023); Guilbert (2024); Nicoletti *et al.* (2025); Stegnar (2025).
Thermal parameters (e.g. heat transfer coefficient, thermal resistance, ventilation)	National regulations on energy performance (Portugal); ; Greek energy efficiency regulations (TEE-KENAK, 2019); TABULA; Geodetic Administration of the Republic of Slovenia (GURS); LNEC – Civil Engineering National Laboratory (Portugal), Housing Census; ISO 6946; RdSAP reference tables; sensors (in-situ measurements); Topographic Objects Database (Poland)	Terés-Zubiaga *et al.* (2013); Walker *et al.* (2014); Mayer *et al.* (2014); Teli *et al.* (2016); Pittam and O'Sullivan (2017); Ramos *et al*. (2017); Papada *et al.* (2018); Papada and Kaliampakos (2019); Spiliotis et al (2020); Szulgowska-Zgrzywa *et al.* (2022); Szulgowska-Zgrzywa *et al.* (2023); Nicoletti *et al.* (2025); Stegnar (2025);
Renovation (status, number of interventions)	Own survey; Public datasets from Ecofund (Slovenia); Social housing public companies	Aranda *et al.* (2018); Guilbert (2024); Stegnar (2025).
Building accessibility	National Statistics	Clavijo-Núñez *et al.* (2024)

In addition to the already reviewed indicators, three Covenant of Mayors indicators are highlighted (Table 3), due to their complementary input. From a policy monitoring perspective, the "share of buildings renovated per year" is a useful indicator to measure progress. Moreover, focusing on energy equipment, the ownership rate of centralised heating and cooling systems is a relevant factor to be examined closely. On the one hand, it is linked to broader and more reliable energy provision, but on the other hand, in certain situations, it can put households in technological and economic lock-in situations that exacerbate their vulnerability (Tirado-Herrero and Ürge-Vorsatz, 2012).

Table 3 - Building indicators from Covenant of Mayors Europe (Based on CoM, 2025)

Indicators	Description	Unit
Share of buildings renovated per year	Share of buildings renovated per year out of total buildings	Percentage
Households with centralised heating system / total households	Share of households with a centralised heating system out of total households	Percentage
Households with centralised cooling system / total households	Share of households with a centralised cooling system out of total households	Percentage

4.2.2 Energy

The energy performance class is a composite indicator that reflects the energy performance of the building envelope as well as the efficiency of its energy equipment. It is a useful and comprehensive indicator to depict the energy dimension of buildings. However, it is not always publicly available, especially at lower spatial scales, and it is often prone to errors in the estimation of building parameters by assessors (Hardy and Glew, 2019), especially since different methodologies and study objects are used (apartment vs whole building). Despite not being evidenced in the review studies, real estate companies and platforms can also be a source of Energy Performance Certificate (EPC) data, although this kind of data is often protected or behind a paywall.

Energy needs, demand and energy consumption are the most used energy-based indicators. There are important distinctions to note. Energy needs are estimations based on physical models that can integrate building, climate, and occupant behaviour parameters to estimate the necessary energy needs according to a specific standard of comfort or level of energy services. These estimations can be conducted by the authors using different sources of data (*e.g.*, Gouveia *et al.*, 2019), or standard estimated values available in regulations, standards, or software calculation tools can also be used. While energy needs only integrate the building's passive elements, it is possible to estimate the energy demand or potential consumption by integrating the active elements, such as HVAC systems, by considering their efficiencies in estimating the amount of final energy necessary to provide the required useful energy (energy need). Several authors take this further step and estimate energy consumption, either by estimating energy needs or by analyzing energy bills (e.g., Vurro et al., 2022; Stegnar, 2025). Other approaches simply access actual (or real) energy consumption levels at either the household (e.g, smart meters) or regional scale and integrate them in the energy poverty assessment, often comparing them to a standard. This is often designated as a "direct measurement" method (Thomson et al., 2017), where households with lower (or higher, in some approaches) energy expenditure than a set estimated standard are considered energy poor (e.g., Spiliotis et al., 2020). It can also serve as a middle step in the process of calculating energy costs/expenditure, a common indicator of energy poverty (*e.g.*, Arsenopoulos et al., 2025). However, this indicator is also used in vulnerability-based measurements, integrated as one of several indicators that are combined to estimate a vulnerability level rather than incidence (*e.g.*, Gouveia *et al*., 2019; Clavijo-Núñez *et al*., 2024; Stegnar, 2025). It is essential to note that the term "energy demand" has often carried a different meaning. In some cases, it is referred to as the real energy consumption, whereas in others, it is considered the estimated potential energy consumption. Energy needs, demand and consumption are often estimated or utilised according to specific energy uses (space heating is the most frequent), per energy source or fuel (e.g. electricity for space cooling), and geographically per unit of area, building type and per region of study. Energy consumption is not only about energy access and energy, but rather about the energy-enabled basic and secondary capabilities, which are fundamental to guaranteeing well-being (Day et al., 2016). Energy poverty relates to a lack or difficulty in accessing energy levels that enable these capabilities; hence, it is relevant to investigate not only energy consumption or expenditure but also whether these capabilities are being met.

Shwashreh *et al.* (2024) include energy supply disconnections in their assessment, an indicator mostly used for energy poverty assessments in Global South nations. However, it remains a significant problem in certain European communities, as exemplified by Varo (2024). Directive (EU) 2024/1711 emphasises the need to "ensure that vulnerable customers and customers affected by energy poverty are fully protected from electricity disconnections". Table 4 shows the energy indicators per data source and study reference. However, data on disconnections are strictly protected due to GDPR and energy companies' business confidentiality, and are only available at the national level.

Table 4 - Energy indicators per data source and study reference

Indicator	Data Source	Reference
Energy Performance Certificate (EPC) Class/SAP class (UK)	Local survey; British Houseshold Panel Survey; Energy Saving Trust	Little *et al.* (2024); Roberts *et al.* (2015); Gupta and Greg (2020)
Energy needs (levels; per energy use, per building typology)	Estimated from other data sources including national statistics and own surveys; Regulatory standards; EPCs;	Teli *et al.* (2016); Nowalska-Kapuścik (2021); Arsenopoulos *et al.* (2025); Clavijo-Núñez *et al.* (2024); Nicoletti *et al.* (2025); Campagnolo (2022); Gouveia *et al.* (2018); Gouveia *et al*. (2019); Horta *et al.* (2019); Spiliotis *et al.* (2020); Katsoulakos (2011)
Energy demand/consumption (per building	Estimated from other data sources, including national statistics and own surveys;	Tirado-Herrero and Ürge-Vorsatz (2012); Kazukauskas and Li (2024); Nowalska-Kapuścik (2021); Papada *et al.* (2018); Teli

typology, per energy use, per fuel/source)	Household Energy Use Surveys; Household budget Survey; Energy companies; Statistical Authorities (Greece); World Health Organisation; EnerPHit standards; ODYSSEE-MURE; smart meters; private building data; General Directorate on Energy and Geology (Portugal)	*et al.* (2016); Mayer *et al.* (2014); Arsenopoulos *et al.* (2025); Rasanga *et al.* (2024); Bissiri *et al.* (2019); Clavijo-Núñez *et al.* (2024); Aranda *et al.* (2017); Caballero *et al.* (2021); Terés-Zubiaga *et al*. (2013); Nicoletti *et al.* (2025); Vurro et al. (2022); Stegnar (2025); Gupta and Greg (2020); Campagnolo (2022); Gouveia and Seixas (2016); Gouveia *et al*. (2019); Horta *et al.* (2019); Gouveia *et al.* (2018); Simões *et al.* (2016); Papada and Kaliampakos (2019); Spiliotis *et al.* (2020); Katsoulakos (2011)
Energy supply disconnections	Own survey	Shwashreh *et al.* (2024)

4.2.3 Economic

In straight connection to the energy dimension, energy prices are an economic indicator that represents a fundamental component in several energy poverty assessment approaches. Taken at face value, it is mostly used as an indirect indicator, linking higher potential vulnerability when prices are higher. Nevertheless, energy prices are a middle indicator used to calculate energy expenditure. This is one of the most common indicators for directly calculating energy poverty incidence and estimating headcounts of the energy poor. It is used to discern two different expressions of energy poverty, as explained by Meyer *et al.* (2018) - abnormally high energy expenditure (measured energy poverty) and abnormally low energy expenditure (hidden energy poverty). Energy expenditures can be estimated from energy prices and energy consumption (*e.g.*, Papada and Kaliampakis, 2019; Spiliotis *et al*., 2020), or taken directly from household energy billing or national or local surveys (*e.g*., Panão, 2021; Lis *et al*., 2016; Aranda *et al*., 2017). Some authors consider total energy expenditure, while separate expenditure for a specific energy service (*e.g.* heating in Bouzarovski, 2007) or fuel *(e.g.*, Strmota and Ivanda, 2021).

Income is the most frequently used indicator in energy poverty assessment approaches. It can also be used at face value, as an individual unit of a multidimensional approach and proxy of affordability (*e.g*., Gouveia *et al*., 2019; Little *et al*., 2024), or integrated in expenditure-based indicators (*e.g*., Sokolowski *et al*., 2023; Szczygiel *et al*., 2024), as abnormally high or low expenditures are estimated against a standard corresponding to a share of expenditure to income. Some authors use an expenditure-to-income ratio as the energy poverty threshold (*e.g*., Bouzarovski and Tirado-Herrero, 2016; Tirado-Herrero and Ürge-Vorsatz, 2012; Sokolowski *et al*., 2023), whether it is fixed percentage (*e.g*., 10% or 20%) or a relative measure (double or half the population's median – 2M or M/2). Other authors use double thresholds (*e.g.* Low Income High Cost indicator), where a household is considered energy poor if expenditure is above a certain threshold and income is below a certain level (*e.g*., Sokolowski *et al*., 2020; Szczygiel *et al*., 2024). The latter has the important advantage of ruling out high-income households as energy poor. Different types of income can be integrated into this approach. Total income refers to income before taxes and social discounts, whereas net income is the income value after those discounts, which more accurately represents the household's purchasing power. Authors like Karpinska and Smiech (2020a) and Karpinska and Smiech (2021) use equivalised disposable income from state and regional-level surveys, which represents the adjusted net income that reflects the size and composition of the household, providing a more accurate depiction of the economic standard of living. Equivalisation can also be applied to energy expenditure, as in Mayer *et al.* (2014). At the area-based level, authors also use income inequality as a proxy measure of potential energy poverty vulnerability (e.g., Bouzarovski and Tirado-Herrero, 2016). Despite not being addressed in these studies, property value can also serve as an income proxy, although this relationship is not always straightforward and needs further research.

Tirado-Herrero and Ürge-Vorsatz (2012) and Grossmann *et al.* (2024) consider other basic expenses in their assessments. This is aligned with authors that defend the Minimum income standard approach to assess energy poverty (*e.g.*, Romero *et al*., 2018; Barrella *et al*., 2022b), integrating a more complete assessment of basic domestic needs expenditure (*e.g.*, water, house, mobility) and their interplay with energy costs. In fact, a household may have adequate levels of energy services at the cost of other basic needs, thus arguably still being in a situation of poverty.

Nicoletti *et al.* (2025) and Rasanga *et al*. (2024) propose two different indicators in their studies. The former integrates renovation costs in the analysis, an important aspect affecting the home's energy efficiency and the household's ability to guarantee adequate energy services. The latter investigates the poverty premium for energy in poor energy consumers, the extra costs these vulnerable consumers have to bear compared to the average consumer. Higher tariffs of pre-paid meters are an example of a poverty premium. It adds an important layer of analysis as it represents an often overlooked cost for these households. Nicoletti *et al.* (2025) also integrate inflation rates to calculate cost-effectiveness of selected renovation measures. Campagnolo (2022) defines future scenarios with different gross domestic product growth rates, aiming to assess the distributional implications of climate change impacts on residential energy demand. Table 5 shows the economic indicators per data source and study reference.

Table 5 - Economic indicators per data source and study reference

Indicator	Data Source	Reference
Energy prices	Fuel prices observatory (Greece); Utilities data (energy companies); Energy regulators; Eurostat; Statistical	Katsoulakos (2011); Walker *et al.* (2014); Paravantis and Santamouris (2014); Roberts *et al.* (2015); Papada *et al.* (2018); Papada and Kaliampakos (2019); Bissiri *et al.* (2019); Ntaintasis *et al.* (2019); Spiliotis *et al.* (2020);

	Authorities (Greece); Statista, UK Government	Campagnolo (2022); Mulder *et al.* (2023); Spandagos *et al.* (2023)
Energy expenditures/costs (modelled or real)	Household Energy Use Surveys; Household Budget Surveys; AWP scheme (public) survey; Energy Saving trust (private); microdata national Statistics (Netherlands); own surveys; Social housing managements companies; National Statistics (Greece); Enable-EU project; European report on the total cost of energy expenditure	Bouzarovski (2007); Tirado-Herrero and Ürge-Vorsatz (2012); Terés-Zubiaga *et al.* (2013); Walker et al. (2014); Mayer et al. (2014); Roberts et al., (2015); Bouzarovski and Tirado-Herrero (2016); Lis *et al.* (2016); Aranda *et al.* (2017); Aranda *et al.* (2018); Gupta and Greg (2020); Antepara *et al.* (2020); Sokolowski *et al.* (2020); Sánchez *et al.* (2020); Gupta and Greg (2020); Karpinska *et al.* (2021); Panão (2021); Strmota and Ivanda (2021); Vurro *et al.* (2022); van Hove *et al.* (2022); Campagnolo (2022); Sokolowski *et al.* (2023); Little *et al.* (2024); Guilbert (2024); Kazukauskas and Li (2024); Shwashreh *et al.* (2024); Szczygiel *et al.* (2024); Arsenopoulos *et al.* (2025); Grossmann *et al.* (2024);
Income (total, net, equivalised net, income inequality)	EU-SILC; Eurostat; Household Budget Survey; primary survey; Statistical Authorities (Greece, Portugal); Enable-EU project; Statista; AWP scheme (public)survey; Energy Saving trust (private); City Statistics (Madrid); Statistics microdata (Netherlands); Social housing Management companies;	Bouzarovski (2007); Katsoulakos (2011); Tirado-Herrero and Ürge-Vorsatz (2012); Walker *et al.* (2014); Paravantis and Santamouris (2014); Mayer *et al.* (2014); Roberts *et al.* (2015); Gouveia and Seixas (2016); Simões *et al.* (2016); Bouzarovski and Tirado-Herrero (2016); Boemi and Papadopoulos (2017); Boemi *et al.* (2017); Papada *et al.* (2018); Aranda *et al.* (2018); Gouveia *et al.* (2018); López-Bueno *et al.* (2018); Gouveia *et al.* (2019); Horta *et al.* (2019); Papada and Kaliampakos (2019); Ntaintasis *et al.* (2019); Bissiri *et al.* (2019); Boemi and Papadopoulos (2019); Spiliotis *et al.* (2020); Sánchez *et al.* (2020); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Antepara *et al.* (2020); Sokolowski *et al.* (2020); Boemi *et al.* (2020); Gupta and Greg (2020); Karpinska and Smiech (2021); Karpinska *et al.* (2021); Nowalska-Kapuścik (2021); Panão (2021); de la Paz *et al.* (2022); Campagnolo (2022); Lyra *et al.* (2022); van Hove *et al.* (2022); Sokolowski *et al.* (2023); Mulder *et al.* (2023); Spandagos *et al.* (2023); Kazukauskas and Li (2024); Guilbert (2024); Shwashreh et al. (2024); Szczygiel *et al.* (2024); Rasanga *et al.* (2024); Little *et al.* (2024); Clavijo-Núñez *et al.* (2024); Nicoletti

		et al. (2025); Stegnar (2025); Arsenopoulos et *al*. (2025).
Other home expenses (food, house, water, mobility, etc)	Household Budget Survey; EU-SILC; interviews.	Tirado-Herrero and Ürge-Vorsatz (2012); Panão (2021); de la Paz *et al.* (2022); Grossmann *et al.* (2024).
Renovations costs	Public online platform	Nicoletti *et al.* (2025)
Poverty Premium	UK Household Longitudinal Survey	Rasanga *et al.* (2024)
Inflation rates	simulated	Nicoletti *et al.* (2025)
Gross domestic product growth	WDI and ISPRA data	Campagnolo (2022)

The Covenant of Mayors Europe proposes additional indicators (Table 6) that were not addressed in the reviewed studies. These are area-based indicators that enable monitoring the impact of policies and interventions in the population of a certain region or district, which can be useful in the context of the LOCATEE project. One of the indicators is a ratio of money spent on energy-poor households in relation to local GDP by the local authority, which provides a measure of the economic commitment and investment to target and mitigate this issue. The other two indicators are also ratios of energy poverty household support in relation to households detected and households asking for support. These provide a picture of the problem's dimension and how effectively the deprived households are being targeted and supported. Within this group, the approach can identify energy poor households based on the recipients of social support, energy grants, or social tariffs (Owen et. al., 2023).

Table 6 - Economic indicators from Covenant of Mayors Europe (Based on CoM, 2025)

Indicators	Description	Unit
Money spent to support energy poor households or persons / in relation to local GDP	Percentage of public funds spent in support programs out of total local GDP	Percentage
Energy poor households / persons supported / total energy poor households asking for support	Percentage of energy poor households / persons that benefit from some kind of support program out of total number of households asking for support	Percentage
Energy poor households / persons supported / total	Percentage of energy poor households / persons that	Percentage

energy poor households detected	benefit from some kind of support program out of total number of energy poor households	

4.2.4 Climate

Authors also take on the climatic aspects in their studies. The most commonly used indicator is the outside temperature, which can be used to characterise climatic conditions in the case-study locations but also as a key component of energy performance and energy needs assessments, especially in the calculation of heating and cooling degree days. These indicators measure the difference between the outside temperature and a standard indoor temperature, and are used to estimate the energy needs for space heating and cooling in buildings. European and national statistics often provide data on heating and cooling degree days with some level of spatial disaggregation, making them a viable indicator for integration into energy poverty studies. Outside temperatures are also easily accessible at regional meteorological institutes through weather stations. Temperatures are also used to assess particular phenomena like urban heat islands (Sánchez et al., 2020). These factors affect urban areas, potentially resulting in higher cooling energy needs in the summer and potentially increased vulnerability.

Climate zones (*e.g.*, Gouveia *et al*., 2019) represent geographical variations in heating and cooling degree days, and are a relevant parameter for estimating a building's energy needs. It is also a useful indicator to depict regional climate severity. Humidity levels are also considered in some studies (Kazukauskas and Li, 2024; Campagnolo, 2022), potentially due to the interplay with outdoor temperature and subsequent impact on energy use and indoor comfort. Vurro *et al.* (2022) utilised climate models to obtain projected climate data, investigating how climate change will impact energy poverty. This analysis can yield important insights for effective future policymaking and roadmapping. The climate indicators, listed by data source and study reference, are presented in Table 7.

Table 7 - Climate indicators per data source and study reference

Indicator	Data Source	Reference
Outside temperatures	Sensors; National Meteorological and Hydrological Services; International Weather for Energy Calculations (IWEC) weather data; tools (*e.g.* DesignBuilder V4.7); CMCC-CM Earth System Model; National regulations; field measurements	Walker *et al.* (2014); Roberts et al., (2015); Simões *et al.* (2016); Boemi and Papadopoulos (2017); Ramos *et al.* (2017); Aranda *et al.* (2018); Bissiri *et al.* (2019); Gouveia *et al.* (2019); Horta *et al.* (2019); Grdenic *et al.* (2020); Sánchez *et al.* (2020); Campagnolo (2022); Mulder *et al.* (2023); Kazukauskas and Li (2024); Arsenopoulos *et al.* (2025).

Heating and cooling degree days	Eurostat, ODYSSEE-MURE; local data (weather stations); National Meteorological and Hydrological Services; British Household Panel Survey	Simões *et al* (2016); Ramos *et al.* (2017); Papada and Kaliampakos (2019); Gouveia *et al.* (2019); Horta *et al.* (2019); Spiliotis *et al.* (2020); Arsenopoulos *et al.* (2025).
Relative humidity	Field measurements; CMCC-CM Earth System Model	Campagnolo (2022); Kazukauskas and Li (2024).
Urban Heat Island	Madrid Urban Climate report	Sánchez *et al.* (2020)
Climate zones	National regulations; International Weather for Energy Calculations (IWEC)	Gouveia *et al.* (2018); Gouveia *et al.* (2019); Horta *et al.* (2019); Arsenopoulos *et al.* (2025); Nicoletti *et al*. (2025).

The Covenant of Mayors proposed two additional climate indicators – heatwaves and cold spells frequency (Table 8) that can provide relevant information for studying the potential impact of climate on the expression of energy poverty. These extreme weather events increase the energy required to maintain healthy temperatures inside the home, which can rapidly drive up energy costs. They are particularly risky for vulnerable segments of the population when the preventive adaptation measures are not taken, potentially leading to an increase in excess mortality in both winter and summer. The city of Buenos Aires (Morel et al.,, 2022) also introduced heat wave risk in their area-based vulnerability mapping.

Table 8 - Climate indicators from Covenant of Mayors Europe (Based on CoM, 2025)

Indicators	Description	Unit
Frequency of heat waves	Frequency of heat waves per month in a year	Number of days/year
Frequency of cold waves	Frequency of cold spells per month in a year	Number of days/year

4.2.5 Sociodemographic Factors and Vulnerable Groups

Several sociodemographic features of households can contribute to exacerbating vulnerability to a potential situation of energy poverty. These characteristics render certain population segments more vulnerable than the average household. They are integrated in multidimensional metrics, used as independent variables to determine their relationship with energy poverty incidence, or considered when selecting the case study population for conducting the analysis. Most of these indicators are available in national statistics and surveys.

One of the most targeted groups is the low-income households, an indicator already addressed in a previous section. These are households in the lower brackets of income (e.g., van Hove *et al*., 2022), who benefit from social protections (e.g., Karpinska *et al*., 2021), and who live in social housing (*e.g*., Shwashreh *et al*., 2024). Their precarious economic conditions result in a decreased ability to afford energy provision, energy efficiency investments, and respond to unexpected rises in energy costs.

Age can also be a factor or added vulnerability. It can be a determinant of the household energy demand. People over 65 years old and children might require higher energy needs than other individuals, thus being considered as potentially vulnerable segments of the population in certain studies (*e.g*., López-Bueno *et al*., 2018; Caballero *et al*., 2021; Nowalska-Kapuścik, 2021). Education level is also integrated in a set of analyses (*e.g*., Boemi *et al*., 2017; Rasanga *et al*., 2024), as it is a predictor of higher income and better living conditions, but might also be related to the households' energy literacy and ability to adapt to increased vulnerability, rendering households with lower education potentially more vulnerable. Household size can also be regarded as a predictor of higher energy poverty vulnerability, as it is associated with higher energy needs and overcrowding. However, this relationship is not always direct.

Specific household type or composition can also reflect added vulnerability. For instance, Middlemiss (2022) identifies single-parent families as vulnerable households. Other examples are pensioners-only households, households with people with mobility issues (Grossmann et al., 2024), and the unemployed with children (Bouzarovski, 2007). Boemi *et al.* (2020) consider marital status as an indicator in their analysis, as it shapes the household composition, power relations within the home, and resilience to shocks.

Employment status is in itself a relevant sociodemographic factor, integrated by several authors (*e.g*., Mayer *et al*., 2014; Boemi *et al*., 2017), directly linked to household income and resilience to unexpectedly high economic burdens. Differences in vulnerability have also been identified across gender (e.g. Sánchez et al., 2020; Nowalska-Kapuścik, 2021), with added vulnerability occurring in female individuals, particularly in single-parent households. The project EmpowerMed focuses deeply on this aspect, highlighting that energy poverty is a form of deprivation with an explicit gender dimension (EmpowerMed, 2025).

Home ownership or tenancy is also a major factor in shaping energy poverty. Owners are in a position of increased power over decisions regarding the dwelling, and thus have a higher degree of freedom and agency within the home to change their environment in efforts to increase comfort and reduce energy consumption. Issues like split incentives often affect tenants' ability to address their potential vulnerability. Riva *et al.* (2021) corroborate that renters are more susceptible to energy poverty.

Ethnicity is a sensitive aspect, and data on it is not collected in every country. Rasanga *et al.* (2024) and Little *et al.* (2024) consider this sociodemographic aspect in their studies, recognising that particular population groups are more vulnerable due to their ethnic background, which correlates to a whole set of difficult socioeconomic conditions and social exclusion issues. Clavijo-Núñez *et al.* (2024) introduce a relevant and also overlooked indicator – the unpaid work or informal work, such as domestic care. This type of work plays a fundamental role within the household and in society as a whole, attending to needs that would otherwise go unmet. As it is unpaid, when it is necessary, it can translate into economic difficulties for the workers. Boemi and Papadopoulos (2019) investigate the relationship between energy poverty and the means of transportation used by households, analyzing the potential interplay between habits, comfort, and vulnerabilities. The choice of a particular means of transportation may be masking a need to save money for other basic necessities, such as energy services. A few authors investigate the relationship of household energy poverty and population density, urbanisation degree and territorial typology (urban/rural), as energy poverty configurations and levels can differ significantly according to these factors (Simcock *et al*., 2021; Dokupilova *et al*., 2024). For instance, Simcock *et al.* (2021) state that in rural areas, access to goods and services is poorer, whereas housing and service costs are higher in urban settings. The sociodemographic indicators, as per the data source and study reference, are displayed in Table 9.

Table 9 - Sociodemographic indicators per data source and study reference

Indicator	Data Source	Reference
Age	EU-SILC, primary surveys and questionnaires, European projects, Household Budget Survey; National Statistics; state programs (AWP scheme); regional agencies, City statistics (Madrid)	Walker *et al.* (2014); Simões *et al.* (2016); Boemi and Papadopoulos (2017); López-Bueno et al. (2018); Gouveia *et al.* (2019); Horta *et al.* (2019); Karpinska and Smiech (2020b); Karpinska and Smiech (2020a); Grdenic *et al.* (2020); Sánchez et al. (2020); Antepara *et al.* (2020); Boemi *et al.* (2020); Karpinska and Smiech (2021); Nowalska-Kapuścik (2021); Caballero et al. (2021); Strmota and Ivanda (2021); Vurro *et al.* (2022); van Hove *et al.* (2022); Little *et al.* (2024); Shwashreh *et al.* (2024).
Education level	EU-SILC, primary surveys and questionnaires, National Statistics, city statistics (Madrid)	Simões *et al.* (2016); Boemi *et al.* (2017); Gouveia *et al.* (2019); Horta *et al.* (2019); Boemi and Papadopoulos (2019); Karpinska and Smiech (2020a); Boemi *et al.* (2020); Karpinska and Smiech (2020b); Sánchez *et al.* (2020); Nowalska-Kapuścik (2021); Karpinska and Smiech (2021); Lyra *et al.* (2022); Rasanga *et al.* (2024); Guilbert (2024).
Household size	EU-SILC, primary surveys and questionnaires, european projects, Household Budget Survey; National Statistics;	Walker *et al.* (2014); Paravantis and Santamouris (2014); Gouveia and Seixas (2016); Boemi and Papadopoulos (2017); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Sánchez *et al.* (2020); Karpinska and Smiech (2021); Strmota and Ivanda (2021); van Hove *et al.* (2022); Shwashreh *et al.* (2024).

Household type	EU-SILC, primary surveys and questionnaires, european projects, Household Budget Survey; National Statistics; city statistics (Madrid)	Bouzarovski (2007); Mayer *et al.* (2014); Bouzarovski and Tirado-Herrero (2016); Boemi *et al.* (2020); Sánchez *et al.* (2020); Karpinska *et al.* (2021); de la Paz *et al.* (2022); Mulder *et al.* (2023); Grossmann *et al.* (2024); Little *et al*. (2024); Nicoletti *et al*. (2025).
Employment	EU-SILC, primary surveys and questionnaires, european projects, Household Budget Survey; National Statistics; Census; City statistics (Madrid)	Bouzarovski (2007); Mayer *et al.* (2014); Roberts *et al.*, (2015); Simões *et al.* (2016); Bouzarovski and Tirado-Herrero (2016);); Boemi *et al.* (2017); Aranda *et al*. (2018); Gouveia *et al.* (2018); Gouveia *et al.* (2019); Horta *et al.* (2019); Boemi and Papadopoulos (2019); Sánchez et al. (2020); Boemi et al. (2020); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Karpinska and Smiech (2021); Karpinska *et al*. (2021); Campagnolo (2022); de la Paz *et al.* (2022); Mulder *et al.* (2023); Rasanga et al. (2024); Grossmann *et al.* (2024); Little *et al.* (2024); Nicoletti *et al.* (2025).
Gender	National Statistics; Census; primary surveys; City statistics (Madrid)	Sánchez *et al.* (2020); Boemi *et al.* (2020); Nowalska-Kapuścik (2021); Sokolowski *et al.* (2023); Shwashreh *et al.* (2024).
Marital status	Own survey	Boemi *et al.* (2020)
Social protection	Surveys; Local data bank	Karpinska *et al.* (2021); Sokolowski *et al.* (2023)Spandagos *et al.* (2023).
Building ownership/tenancy	EU-SILC; National Statistics; Census; primary surveys;	Roberts *et al.* (2015); Gouveia *et al.* (2019); Horta *et al.* (2019); Grdenic *et al.* (2020); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Karpinska and Smiech (2021); Lyra *et al.* (2022); Mulder et al. (2023); Rasanga *et al.* (2024); Guilbert (2024).
Ethnicity	National Statistics; Census	Rasanga *et al.* (2024); Little *et al.* (2024)
Informal work	National Statistics (Spain)	Clavijo-Núñez *et al.* (2024)
Means of transportation	Own questionnaires	Boemi and Papadopoulos (2019)
Population density/Urbanisation degree	EU SILC; Household Budget Survey (Poland)	Bouzarovski and Tirado-Herrero (2016); Lis *et al.* (2016); Karpinska *et al.* (2021); Aristondo *et al.* (2024); Stegnar (2025).
Territory typology (rural/urban)	Household Budget Survey (Poland); own survey	Gouveia *et al.* (2018); Sokolowski *et al.* (2020); Karpinska *et al.* (2021).

In connection with household type, the Powerpoor project collects data on the number of dependent children, considering it a factor of increased burden and vulnerability for households (PowerPoor, 2025). The city of Seattle, part of the C40 network (Morel, et al., 2022), created an Environmental Equity Assessment that integrates the factors of income, race, linguistically isolated households and foreign-born population. The latter three factors are often overlooked issues in energy poverty studies and can be important determinants of vulnerability.

4.2.6 Other Indicators

Other indicators are used by authors to identify potential situations of energy poverty in households. Self-reports of difficulties or preferences regarding energy needs, housing conditions, and other related aspects are a valuable source of information regarding potential household vulnerability and clear signs of an energy poverty problem, often used as direct indicators of energy poverty. The EU-SILC consensual indicators or analogous indicators are examples of frequently used indicators to depict effects of energy poverty, such as difficulty in paying utility bills, maintaining comfortable indoor temperatures, and keeping the home in a good state of conservation (*e.g.*, Karpinska and Smiech, 2020a; de la Paz *et al*., 2022). These are easy to apply and can be transferred to other contexts. Other authors use similar indicators oriented towards satisfaction instead of difficulty, regarding indoor temperature, heating system, housing conditions, and other factors (*e.g.*, Szulgowska-Zgrzywa *et al*., 2020; Boemi and Papadopoulos, 2017; Nowalska-Kapuścik, 2021).

Some authors (*e.g.*, Mayer *et al*., 2014; Antepara *et al*., 2020) consider home occupancy a crucial factor in energy poverty assessment, as spending a higher percentage of the day at home may translate to increased energy needs within the home. It can also be a proxy of unemployment and other socioeconomics predicaments.

Energy behaviours can also unveil situations of restricted energy use or another sort of energy deprivation. Reducing the use of the heating system (*e.g.*, Aranda *et al*., 2018; Grdenic *et al.*, 2020) or other energy coping mechanisms are often a sign of an attempt to keep energy bills at an affordable level. The heating regime (*e.g.*, Walker *et al*., 2014; Aranda *et al*., 2017) or thermostat setting options (*e.g.*, Gupta and Greg, 2020) can unveil situations of self-restriction in energy use. The project PowerPoor asks households about their thermostat settings in their PowerTarget survey (PowerPoor, 2025). Switching energy suppliers (Spandagos *et al*., 2023) can be a coping mechanism for some families. The temperature at which equipment is turned on (*e.g.*, Boemi and Papadopoulos, 2019) can also uncover self-restrictive behaviour. Plans to disconnect from district heating energy supply due to the system's inefficiency (*e.g.*, Tirado-Herrero and Ürge-Vorsatz, 2012) are another example. Caballero and Della Valle (2021) state that research has identified energy behaviour, namely the occupation of household spaces and failure to adopt "adaptive thermal comfort," as significant determinants of energy poverty. The restriction of other basic needs can also be linked to energy affordability (*e.g.*, Ntaintasis *et al*., 2019). Energy behaviour can be intrinsically related to the building type where the household resides.

Lighting (addressed in *e.g*., Aristondo *et al*., 2014; Spandagos *et al*., 2023) is an underexplored aspect that holds a connection to energy poverty through the housing dimension. Homes with poor lighting receive less sunlight, which impacts their thermal performance and energy requirements in both summer and winter seasons. Darker homes can also have a negative impact on occupants' quality of life.

Indoor temperature (and humidity in complement) is another indicator that can be used as a direct measure of energy poverty (direct measurement approach), when the measured value is compared to a comfort standard. However, differences can be explained by personal preferences as thermal comfort is highly subjective; thus, it should be complemented with other indicators. Authors in this review used it as a complementary indicator rather than a direct measure (*e.g*., Ramos *et al*., 2017; Caballero *et al*., 2021; Terés-Zubiaga *et al*., 2013).

Indoor air quality indicators are also used by a few authors (*e.g.*, Terés-Zubiaga *et al*., 2013; Caballero *et al*., 2021; Aristondo *et al*., 2024). Poor air quality can be correlated with inadequate ventilation and old, inefficient heating equipment, such as open fireplaces, which relate to the building type. It may be a sign of energy precarity, as often observed in rural households (Stojilovska *et al*., 2021). Greenhouse gas emissions (*e.g*., Campagnolo, 2022; Stegnar, 2025) are another negative externality associated with inefficient energy equipment and the use of fossil fuels. Palma *et al.* (2024) argue that a household locked in a situation where it cannot afford to stop using fossil fuels and switch to cleaner fuels or equipment can be considered a situation of energy poverty. Noise (*e.g*., Aristondo *et al*., 2024) is not a common indicator in energy poverty studies, and the link between noise and energy poverty is even less straightforward. However, it can be argued that it is linked to poor housing conditions, namely, thin and poorly insulated walls and roofs. It is particularly relevant in apartment buildings, as it is more challenging to avoid neighbours' noise due to their proximity too. In connection with noise and air quality, Boemi and Papadopoulos (2019) introduce the dimension of outdoor space (presence of green spaces in the surroundings) as a factor in energy poverty. In fact, green spaces can have a positive impact on air quality and noise within dwellings.

Health issues and mortality represent a potential consequence of energy poverty and have therefore been increasingly included in energy poverty assessments (Ntaintasis et al., 2019; Sokolowski *et al*., 2023). Poor health, in general, and respiratory, cardiovascular, and musculoskeletal issues in particular, have been associated with a lack of adequate energy services. Health can be measured through various types of indicators, including self-diagnoses, doctor diagnoses, doctor visits, and hospital stays (Sokolowski *et al.*, 2023). Health conditions can be part of several factors that drive higher household vulnerability. On the other hand, they can also be partially created and exacerbated by inadequate levels of energy services. However, it should be noted that health conditions are caused by a multitude of factors and are not solely attributed to a situation of insufficient energy services; thus, this association should be viewed as a complementary assessment.

Potentially linked to educational levels indicator, energy literacy is also a relevant indicator to consider, integrated by Caballero *et al.* (2021) in their study. It influences a range of energy behaviours and choices, from the energy system and fuel the household decides to use to which energy provider is contracted.

Finally, personal identity, interests, and daily habits may provide useful insights into how households interact with energy in their lives. Caballero *et al.* (2021) investigate the pro-environmental self-identity, altruism, trust, reciprocity, group identity, and intertemporal preferences of households, which can significantly shape their choices regarding energy consumption. Nowalska-Kapuścik (2021) explores daily activities such as free time, meal planning, recycling, and rational consumption, which can also be linked to emotions surrounding environmental and economic issues and subsequently influence a person's perspective on energy provision. Feelings and interest in this issue can also play a role in shaping decisions. Gupta and Greg (2020) investigated the household interest in energy efficiency interventions, as their increasing interest and belief in its effectiveness can be a significant lever to prompt a decision towards adoption. These alternative indicators are presented in Table 10, organised by data source and study reference.

Table 10 - Other indicators per data source and study reference

Indicator	Data Source	Reference
Self-reported difficulties and preferences (energy bills, dwelling conditions, restriction of basic needs)	EU-SILC; surveys and questionnaires;	Terés-Zubiaga *et al.* (2013); Teli *et al.* (2016); Bouzarovski and Tirado-Herrero (2016); Boemi *et al.* (2017); Boemi and Papadopoulos (2017); Boemi and Papadopoulos (2019); Ntaintasis *et al.* (2019); Horta *et al*. (2019); Karpinska and Smiech (2020a); Karpinska and Smiech (2020b); Boemi *et al.* (2020); Szulgowska-Zgrzywa *et al.* (2020); Grdenic *et al.* (2020); Karpinska and Smiech (2021); Nowalska-Kapuścik (2021); de la Paz *et al.* (2022); Lyra *et al.* (2022); Shwashreh *et al.* (2024); Szczygiel *et al.* (2024); Clavijo-Núñez *et al.* (2024); Aristondo *et al*. (2024).
Home occupancy	Own survey; National Statistics	Mayer *et al.* (2014); Antepara *et al.* (2020); Little *et al.* (2024)
Energy Behaviours	surveys and questionnaires	Tirado-Herrero and Ürge-Vorsatz (2012); Terés-Zubiaga *et al.* (2013); Walker *et al.* (2014); Teli *et al.* (2016); Gouveia and Seixas (2016); Aranda *et al.* (2017); Boemi and Papadopoulos (2017); Aranda *et al.* (2018); Bissiri *et al.* (2019); Horta *et al.* (2019); Boemi and Papadopoulos (2019); Ntaintasis *et al.* (2019); Grdenic *et al.* (2020);

		Gupta and Greg (2020); Grossmann *et al.* (2024); Clavijo-Núñez *et al.* (2024).
Indoor temperature and humidity	Sensors; surveys;	Terés-Zubiaga *et al.* (2013); Paravantis and Santamouris (2014); Ramos *et al.* (2017); Boemi and Papadopoulos (2017); Boemi *et al.* (2020); Caballero *et al.* (2021); Guilbert (2024).
Indoor Lighting	EU-SILC; surveys	Karpinska and Smiech (2020b); Spandagos *et al.* (2023); Aristondo *et al.* (2024).
Indoor air quality	Sensors; surveys	Terés-Zubiaga *et al.* (2013); Caballero *et al.* (2021); Aristondo *et al.* (2024).
Greenhouse gas emissions	modelled	Campagnolo (2022); Stegnar (2025).
Noise	EU SILC; surveys	Boemi and Papadopoulos (2017); Aristondo *et al.* (2024).
Outdoor Space	questionnaires	Boemi and Papadopoulos (2019)
Health and mortality	EU-SILC; surveys and questionnaires; Census (UK); Madrid Health	Teli *et al*. (2016); Boemi and Papadopoulos (2017); López-Bueno *et al*. (2018); Boemi and Papadopoulos (2019); Ntaintasis *et al.* (2019); Boemi *et al.* (2020); Karpinska and Smiech (2020b); Nowalska-Kapuścik (2021); Sokolowski *et al.* (2023); Szczygiel *et al*. (2024); Little *et al.* (2024); Clavijo-Núñez *et al.* (2024).
Energy Literacy	surveys	Caballero *et al*. (2021)
Personal identity, interests and habits	surveys	Gupta and Greg (2020): Nowalska-Kapuścik (2021); Caballero *et al.* (2021)
Knowledge and literacy	surveys	Guilbert (2024)

The Renoverty project developed a composite energy and transport poverty indicator to identify potential hotspots of energy and transport poverty in European rural areas. Besides energy and transport expenditure, consumption and risk of poverty, it also introduced an accessibility score, quantifying the number of average vehicles per household and railway network passenger intensity and multimodal potential accessibility of a region to assess potential vulnerability, establishing a straight link between energy and transport vulnerability.

The Covenant of Mayors proposes indicators aimed at monitoring policy and regulatory actions related to energy poverty, which are potentially useful for policymakers as well as scholars seeking to investigate the progress made in the policy sphere. They are not crafted to measure energy poverty but rather the political efforts to address it. They consist of a set of checkpoints, such as the existence of an energy poverty strategy, rent regulation, specific energy poverty measures, and incentives for landlord programs at the local or municipal level. The same approach could be applied to other measures and programs, such as disconnection protection, social energy tariffs, or subsidies for energy renovations. Two other indicators are proposed to assess the targeting of energy-poor households, a key factor in the success of energy poverty policies, and engagement and cooperation with local stakeholders, which are also decisive factors in nationwide energy poverty mitigation strategies. These indicators are displayed in Table 11.

Table 11 - Policy and regulatory framework and participation/awareness-raising indicators from Covenant of Mayors Europe (Based on CoM, 2025)

Indicators	Description	Unit
Existence of energy poverty strategy	Yes or no answer to the question: "Is there an energy poverty strategy"?	Yes / No
Existing rent regulation	Yes or no answer to the question: "Are there rent regulation"?	Yes / No
Specific measures related energy poverty	Yes or no answer to the question: "Are there energy poverty specific measures"?	Yes / No
Existing incentives for landlord's programs	Yes or no answer to the question: "are there incentives/programs for landlords"?	Yes / No
Awareness-raising campaigns targeting vulnerable households	Preventing rent increases due to energy retrofits, balancing the PRS with interest in homeownership and social housing	Yes / No
Engagement and cooperation with local stakeholders on energy poverty	Yes or no answer to the question: "Is there engagement and cooperation with local stakeholders for energy poverty reduction"?	Yes / No

The EmpowerMed project highlights two other behaviours that could be signs of energy poverty - people spending more time in warm public areas, such as shopping centres or libraries, during cold or hot weather and a continued presence inside the home. These are coping behaviours to deal with the extreme temperatures. Reluctance to have visitors can also be a symptom of energy poverty, as certain households do not want to receive people in their home if they are not able to maintain a comfortable temperature indoors (EmpowerMed, 2025). In their local surveys, the Reverter project inquired about the households' ability to live comfortably with their income in winter and summer months, considering the increase in energy needs, as well as cutbacks on energy use. It also investigated types of tariffs and if households read bills and check meters. Participation in energy efficiency programs was also investigated, aiming to understand reasons for not participating, including affordability problems, unawareness about the existence of these programs, and perceptions on the state and energy suppliers (Reverter, 2025). The city of Warsaw (Morel et al., 2022) collected information on why people did not want to change their energy source for heating and cope with shifts through retrofitting, aiming to understand the political and cultural aspects of energy in their lives.

5 Recommendations for Indicators Selection

This analysis led to the development of a set of recommendations regarding data availability, data sources, indicator types and uses, and aspects to consider for the creation of a comprehensive, inclusive, yet operational local energy poverty measurement within the context of the LOCATEE project for the toolkit design. They summarize the key learnings from this review while guiding local stakeholders in their efforts to detect energy poverty. Several of these recommendations depend on the availability of data resources in the specific geographical contexts of Piraeus (Greece), Rumia (Poland), and Torres Vedras (Portugal). In contrast, others can be implemented using nationally available statistics.

- **National statistics are key** – This review has demonstrated the potential of public national statistics in providing multiple indicators that can serve as starting points for local energy poverty assessments. Comprehensive national public statistics are crucial for designing robust, multilevel energy poverty assessment frameworks.
- **Searching for other sources -** Companies, public institutions and departments, national agencies, European and national projects, articles, and NGOs, can also be important sources of data for energy poverty studies.
- **Accessing regional and local datasets** – Regional and local datasets provide valuable insights into local realities. They can be collected by authorities, as well as by other local stakeholders, highlighting once again the importance of collective efforts at the local scale, from diagnosis to action.
- **Own data collection unlocks detail and nuance** – The review highlights the potential of own data collection as a means to delve deeper into this issue and capture nuance and detail to a higher degree, unveiling situations that would otherwise be hidden. They also offer the possibility to replicate indicators available at the national level.
- **Other indicators might take an important role** – Other indicators and data sources that have not been directly identified in this review (*e.g.,* disconnection risk, digital literacy, technological aptitude, property value) might offer important insights for a more robust energy poverty assessment, provided they can depict relevant determinants.
- **Indicators for multifamily building assessments -** Certain factors, such as tenancy, type of equipment, energy performance, energy needs, type and access to retrofitting, decision-making ability, relations with neighbours, and governance, are shaped by the building type, leading to important differences in the expression of energy poverty.
- **Summer energy poverty is an urgent reality** – Most studies still focus on winter and heating, but heatwaves and increases in summer temperatures due to climate change are calling for more studies and indicators on cooling and summer energy poverty.

- **Address multiple dimensions** – Energy poverty is a multidimensional problem that requires assessments that delve into its various causes and effects for a more comprehensive and nuanced analysis. Available data enable the inclusion of several critical determinants (such as building energy performance and efficiency, income levels, energy expenditure, climate, social vulnerability factors), especially considering that possibilities are limited at the local or building level.
- **Building dimension is key to linking diagnosis with mitigation action -** Assessing building energy efficiency and its connection to energy poverty levels is fundamental to evaluating the potential impact of practical solutions for mitigating vulnerability to this issue. It is a crucial aspect for the development of the LOCATEE toolkit.
- **Testing the real impact of solutions** – Using control and treatment groups can enable a more robust assessment of the real impact of measures in alleviating energy poverty.
- **Develop a comprehensive measurement** – Most studies focus on measuring the headcount of people in energy poverty. Still, there are important aspects for a comprehensive approach, such as depth (how deep is this deprivation) and persistence (for how long households have been suffering from this problem.
- **Focus on capabilities, not just energy consumption** – Energy poverty relates to a lack or difficulty in accessing energy levels that enable certain capabilities; hence, it is relevant to investigate not only energy consumption or expenditure but also whether these capabilities are being met.
- **Tackling the objective and subjective dimensions** – Energy poverty manifests in both objective and subjective expressions; thus, it should be assessed by addressing both objective material lack and perceptions and experiences related to this deprivation. The complementarity of both approaches reduces the exclusion of false negatives.
- **Intersecting dimensions in direct measurements** – Objective measurements often focus on expenditure and income, placing the emphasis on the economic dimension. Approaches that intersect the economic dimension with building and social deprivation in the direct identification of these households are more prone to unveil where the problem might stem from, pointing to possible solutions.
- **Multiple material deprivations can be linked** - A household might enjoy adequate levels of energy services and apparently not suffer from energy poverty. Still, it may be restricting its consumption of other basic needs. Thus, deprivation of all fundamental goods and services (food, water, transport, etc.) necessary for a decent standard of living should be investigated jointly.
- **Energy poverty is not necessarily income poverty** – Despite being often connected, a household might struggle to afford adequate levels of energy even if it is not in

economic poverty. Energy poverty is influenced by a multitude of factors, not just economics.

- **Self-reports constitute a more bottom-up approach** - Self-reports on the experiences of households related to conditions, difficulties, and preferences enable a more democratic, participatory, and bottom-up measurement approach, which can be complemented with more objective metrics.
- **Stakeholder engagement for a more democratic approach** – involving different stakeholders in the data and indicator selection can also contribute to a more democratic measurement process, legitimising the tools and decisions taken and potentially leading to a more inclusive approach. It is an overlooked aspect in the reviewed energy poverty detection approaches.
- **Energy poverty is more than just energy provision** - Energy justice issues, such as the ability to participate in the energy transition, access clean fuels and equipment, and participate in decision-making, are all relevant aspects that can be directly linked to determining energy poverty.
- **Projections for more effective policymaking** – Data is available for future projects regarding indicators such as climate variables that can be used to predict changes in energy poverty vulnerability, potentially supporting the design of plans and roadmaps.

6 Conclusions

Energy poverty detection and mitigation at the local and regional scales is a policy priority in the European Union, as highlighted by the European Commission in the two recommendations on energy poverty for Member States. Local authorities have a key role in driving change at the ground level, due to their proximity, trust, and in-depth knowledge of local realities. However, they need to be supported in their efforts, which is precisely the purpose of a project like LOCATEE. The project aims to bridge the gap between research and local practice, uniting diverse stakeholders under a shared goal. Before taking action, conducting a comprehensive assessment that identifies the various aspects that determine vulnerability within a particular population and territory is advisable. This review compiles and assesses existing practices on energy poverty indicators and data, as well as best practices in measurement, to inform the development of a toolkit that will link diagnosis and the impact assessment of various building interventions. The toolkit will support the project municipalities in identifying energy-poor households within their territories and selecting the most effective measures and actions to address this condition. **The review identifies several data sources, datasets, and indicators that are currently available and can be utilized to construct robust energy poverty measurements, with a particular focus on administrative data at various spatial scales.** The project's goal is to tap into the potential of these datasets, which are often underutilised and whose availability is granted by the municipalities. Moreover, national statistics from central administrations are often spatially disaggregated and serve as a valuable data source to complement regional datasets. Drawing on the identified indicators and data from these energy poverty analyses, the next step is to investigate the availability of administrative data for the project's municipalities and verify the availability of the identified data at the national level, to start designing and crafting the toolkit in its energy poverty detection capacity. **This report also highlights indicators, generally collected in dedicated surveys and questionnaires, for which data might not be available and that could contribute to increasing the comprehensiveness and nuance of assessments.** One relevant limitation of this study is the limited selection of grey literature analysed, which leaves out other publications that could potentially provide insight into further datasets collected at the regional and local levels. Nevertheless, it draws a potential avenue for the continued improvement of the municipal toolkits in the years to come. Only with sustained capacity and knowledge building at the local level, as well as further investment in resources, including data, can the just energy transition be successfully carried out.

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Appendices

Table A1 – Reviewed scientific articles per country

Country	Article reference

Portugal	Gouveia and Seixas (2016); Simões *et al.* (2016); Ramos *et al.* (2017); Gouveia *et al.* (2018); Gouveia *et al.* (2019); Horta *et al.* (2019); Antepara *et al*. (2020); Panão (2021); Nicoletti *et al.* (2025).
Poland	Bouzarovski and Tirado-Herrero (2016); Lis *et al.* (2016); Karpinska and Smiech (2020a); Sokolowski *et al.* (2020); Szulgowska-Zgrzywa *et al.* (2020); Karpinska and Smiech (2020b); Karpinska and Smiech (2021); Karpinska *et al.* (2021); Nowalska-Kapuścik (2021); Szulgowska-Zgrzywa *et al.* (2022); van Hove *et al.* (2022); Sleszynski (2023); Sokolowski *et al.* (2023); Szulgowska-Zgrzywa *et al.* (2023).
Greece	Katsoulakos (2011); Paravantis and Santamouris (2014); Boemi and Papadopoulos (2017); Boemi *et al.* (2017); Papada *et al.* (2018); Boemi and Papadopoulos (2019); Ntaintasis *et al.* (2019); Papada and Kaliampakos (2019); Boemi *et al.* (2020); Antepara *et al.* (2020); Spiliotis *et al.* (2020); Lyra *et al.* (2022); Arsenopoulos *et al.* (2025)
Spain	Terés-Zubiaga *et al.* (2013); Aranda *et al.* (2017); Aranda *et al.* (2018); López-Bueno *et al.* (2018); Sánchez *et al.* (2020); Antepara *et al.* (2020); de la Paz *et al.* (2022); van Hove *et al.* (2022); Clavijo-Núñez *et al.* (2024); Aristondo *et al.* (2024).
United Kingdom	Walker *et al.* (2014); Roberts *et al.* (2015); Teli *et al.* (2016); Bissiri *et al.* (2019); Gupta and Greg (2020); Spandagos et al. (2023); Shwashreh *et al.* (2024); Rasanga *et al.* (2024); Little *et al.* (2024).
Italy	Caballero *et al.* (2021); van Hove *et al.* (2022); Vurro *et al.* (2022); Campagnolo (2022).
Others	Bouzarovski (2007); Tirado-Herrero and Ürge-Vorsatz (2012); Mayer *et al.* (2014); Bouzarovski and Tirado-Herrero (2016); Pittam and O'Sullivan (2017); Bissiri *et al.* (2019); Grdenic *et al.* (2020); Strmota and Ivanda (2021); van Hove *et al.* (2022); Spandagos *et al.* (2023); Mulder *et al.* (2023); Kazukauskas and Li (2024); Szczygiel *et al.* (2024); Grossmann *et al.* (2024); Guilbert (2024); Stegnar (2025).

*Others: Bulgaria, North Macedonia, Lithuania, Netherlands, Ireland, Czechia, Switzerland, Slovenia, Serbia, Norway, Ukraine

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