Key Fuel Poverty Indicators and Variables: A Systematic Literature Review

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ABSTRACT

Fuel poverty is a condition associated with the inability to afford sufficient energy services in a home, especially heating. There is no single standardised process for defining or measuring fuel poverty. Each different method used in research or policy presents biases, resulting in different numbers of affected households with implications for interventions. This systematic literature review aims to summarise the patterns and trends in the indicators and variables of fuel poverty found in relevant publications, as well as the prevalence of associated issues. This study analysed the strengths and weaknesses of the key indicators and variables, showing their biases and opportunities for improvement. The eighty-four publications analysed were selected according to the most relevant results found on Google Scholar searching for definitions and indicators of fuel poverty/energy poverty/energy hardship. The prevalence of relevant themes was identified using NVivo. Understanding the background and the strengths and weaknesses of common indicators and variables of fuel poverty can help develop efficient and effective policies and interventions.

Keywords: Fuel poverty, Energy poverty, Energy Hardship, Systematic Literature Review

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1. INTRODUCTION

Fuel poverty results from issues such as high energy prices, low wages, poor housing quality, and the use of old appliances (Boardman 2013), and improving those issues is essential to protect vulnerable households (Chawla and Pollitt 2013). In addition, fuel poverty can cause severe impacts on the affected households, including financial stress and damage to their physical and mental health (Baker, Mould, and Restrick 2018). Unfortunately, there are no unified indicators or variables to measure fuel poverty (Barrella et al. 2021), and the chosen methods mainly depend on policy purposes and political processes (Boardman 2013).

The literature on fuel poverty has many case studies, and novel metrics (Besagni and Borgarello 2019; Pino-Mejías et al. 2018; März 2018). Publications comparing indicators and variables do not assess their frequency and trends. Thus this study aimed to fill this gap. To the authors' knowledge, this is the first systematic literature review focused not only on the indi-

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cators, but also of household characteristics related to the issue of fuel poverty: home tenure, presence of household members who are children or elderly, associated health conditions, and food issues. A couple of articles published in 2021 discussed indicators and variables (Siksnelyte-Butkiene 2021; Siksnelyte-Butkiene et al. 2021). However, they explore fuel and energy poverty and focus on composite variables and indexes.

This systematic literature review aims to present trends on how fuel poverty is defined and measured by specific variables and associated issues. The research questions for this study are: Which countries/regions lead the literature in fuel poverty? What are the predominant fuel poverty variables, and how do they relate to the perception of the issue? In our study, the trends observed can assist policymakers and researchers in comparing and selecting the indicators and variables focused on their particular priorities.

2. METHODS

2.1. Search and selection criteria

A systematic literature review is a type of publication with specific and replicable criteria for selecting the pool of publications to be analysed to discuss the themes and patterns found in them (Levenda, Behrsin, and Disano 2021). The database used for this study was Google Scholar, and the following searches were performed in February 2023:

- Fuel poverty definition (about 807,000 results),
- Fuel poverty indicator (about 375,000 results),
- Energy poverty definition (about 2,780,000 results),
- Energy poverty indicator (about 1,130,000 results),
- Energy hardship definition (about 184,000 results), and
- Energy hardship indicator (about 83,500 results).

All the searches were sorted by relevance. Only the first twenty results of each search were selected, including grey literature. Several of the same results were shown using different search criteria. Removing duplicates and results not focused on energy affordability issues resulted in eighty-four publications (Appendix A).

Fuel poverty is the term created in the United Kingdom to refer to energy affordability issues from heating a dwelling, but it evolved beyond heating needs (Boardman 2013). Energy poverty (mostly used in the European Union) can refer to fuel poverty, and it is a term that also relates to the struggles of less industrialised countries and their lack of modern energy infrastructure (Li et al. 2014), the latter not being within the scope of this study. Energy hardship was included as it is officially used in New Zealand to refer to the lack of obtaining and affording energy services (Brabo-Catala, Collins, and Barton 2022; Ministry of Business Innovation & Employment 2022a).

2.2. Analysis

The selected articles were analysed to identify and categorise the fuel poverty indicators and variables used, as well as identifying the country of study, equivalisation of income, and use of actual or required energy expenditure. Materials without original research content (without actually calculating fuel poverty) had their indicators and variables selected according to the ones discussed in the text. Manuscripts that used an official indicator of fuel poverty were assumed to follow their specific guidelines.

The type of indicator used can be exactly as the reference mentioned (meaning that the authors calculated fuel poverty using the existing official protocol) or based on the reference (meaning some minor modifications in variables but still strongly connected to the reference). A few articles use novel indicators, not falling into any selected types discussed in this paper. Additionally, most publications used more than one indicator to compare the results. This study focused on eight main types of indicators of fuel poverty:

- 10% —Essentially meaning that fuel poor households are those with energy expenditure above the threshold of 10% of their income (Boardman 1991).
- 2x Mean—Fuel poor households are those with a share of energy expenses over income of at least two times the mean energy expenditure (Isherwood and Hancock 1979).
- 2x Median—Fuel poor households are those with a share of energy expenses over income of at least two times the median energy expenditure (Isherwood and Hancock 1979).
- Median/2—Fuel poor households are those with a share of energy expenses over income of less than half the median energy expenditure (Rademaekers et al. 2016).
- After Fuel Costs Poverty (AFCP)—The main idea being that fuel poor households are those that fall below the poverty line after energy expenditure (Hills 2011).
- Low Income High Costs (LIHC)—Can be summarised as fuel poor households being those with above-median energy expenditure and fall below the poverty line after that expense (Hills 2012).
- Minimum Income Standard (MIS)—Can be shortened as fuel poor households being those that cannot afford energy expenditure after paying for other established basic expenses (Moore 2012).
- Subjective—Fuel poor households are those that report being unable to pay their utility bills, having inadequate heating systems at home, or other subjective parameters relating to fuel poverty, often mixed with self-reported objective variables relating to housing quality (Healy and Clinch 2002).

Authors considered the following variables selected for analysis to be relevant for measuring fuel poverty and discussing associated issues, and they are used for determining not only the prevalence of fuel poverty itself but also its risk. It is uncommon to define fuel poverty using a single variable. The variables selected for the analysis are:

- Ability to maintain home warm (subjective),
- Age of dwelling (objective),
- Age of household members (objective),
- Arrears on energy or other utility bills (subjective),
- Damp walls, floor, or foundation (objective),
- Dwelling type (objective),
- Employment status (objective),
- Fuel prices (objective),
- Income (objective),
- Leaking roof (objective),
- Rot on window frames or floor (objective),
- Size of dwelling (objective),
- Size of household (objective), and
- Tenure (objective).

Equivalisation means adjusting the income according to a household's composition (Hills 2012). It was chosen as a category of analysis since the debate in the literature about whether income should be proportional to the number of household members as equivalising or not presents biases on the number of households in fuel poverty as well as which groups are considered a priority for policies (Boardman 2013). Additionally, some publications use both equivalised and unequivalised income for their calculations and discussions.

Actual or required energy expenditure was another category of analysis, as some manuscripts define fuel poverty using the household's actual expenses. In contrast, others use the required (estimated) energy costs according to characteristics such as their demographic conditions, housing characteristics and fuel prices in that region for that period (Antepara et al. 2020).

2.3 Themes

The selected articles were analysed using NVivo (March 2020 version) to identify topics found to be common or relevant (trends) to fuel poverty. The topics and keywords used for NVivo were the following (all of them selecting only valid results for the topic and allowing for synonyms):

- Children: child children young baby infant kid,
- Elderly: elderly senior old pension retired retirement 60 65,
- Food: food foods feed eat meal meals meat protein cook cooking stove refrigerator freezer microwave,
- Health: disability ill infirm chronic handicap disorder sick health,
- Tenure: tenure tenant tenancy homeowner owner ownership landlord rental rent.

3. RESULTS

3.1 Areas of analysis

Many publications considered multiple countries of analysis, mostly being Europe or the European Union (EU). The United Kingdom (UK, including England, Scotland, Wales, and Northern Ireland) was the most popular country, being analysed in 21.34% of the publications. Europe/EU was analysed in 15.48% of publications, and the USA in 14.29%. All the areas analysed in three or more manuscripts are in Table 1.

TABLE 1
Areas analysed in three or more publications

Area	Number of publications	Percentage of total
UK	18	21.43%
Europe/EU	13	15.48%
USA	12	14.29%
Australia	12	14.29%
France	6	7.14%
New Zealand	4	4.76%
Germany	3	3.57%
Italy	3	3.57%
Spain	3	3.57%

3.2 Type of indicator

The prevalence of selected indicators can be seen in Table 2 below, with the subjective being the most popular one (60.71% of the publications), followed by the 10% indicator (59.52%) and the LIHC (38.10%):

TABLE 2
Prevalence of main types of indicators

Indicators	Number of publications	Percentage of total
Subjective	51	60.71%
10%	50	59.52%
LIHC	32	38.10%
2x median	16	19.05%
MIS	11	13.10%
AFCP	7	8.05%
2x mean	5	5.95%
Median/2	5	5.95%

3.3 Type of variable

The top three objective variables were more frequent than the subjective ones (Table 3). The most popular objective ones were income (70.24% of the publications), equally followed by the size of household (51.19%) and age of household members (51.19%). As for the subjective variables, the ability to maintain the home warm (44.05% of the publications) had the same frequency as arrears on utility/energy bills.

TABLE 3
Frequency of selected variables

Subjective variables	Number of publications	Percentage of total
Ability to maintain home warm	37	44.05%
Arrears on utility/energy bills	37	44.05%
Objective variables	**Number of publications**	**Percentage of total**
Income	59	70.24%
Size of household	43	51.19%
Age of household members	43	51.19%
Size of dwelling	26	30.95%
Fuel prices	22	26.19%
Dwelling type	20	23.81%
Damp walls, floor, or foundation	19	22.62%
Age of dwelling	16	19.05%
Employment status	16	19.05%
Leaking roof	13	15.48%
Rot on window frames or floor	12	14.29%
Tenure	6	7.14%

3.4 Equivalisation of income

Equivalisation, meaning making a household's income proportional to its composition, was not the most frequent way of considering income for calculating fuel poverty, being pres-

ent in 47.62% of the publications (Table 4). The majority, 51.19% of the publications, opted for not equivalising incomes. Additionally, 29.76% of the publications did not consider income as a variable. Multiple publications used both equivalised and unequivalised incomes.

TABLE 4
Presence of equivalisation of income

Types of income	Number of publications	Percentage of total
Unequivalised	43	51.19%
Equivalised	40	47.62%
Not a variable	25	29.76%

3.5 Actual or required energy expenditure

The type of household energy expenditure can be seen in Table 5 below, with half of publications considering the actual energy expenditure used by a household:

TABLE 5
Type of energy expenditure

Energy expenditures	Number of publications	Percentage of total
Actual	42	50.00%
Required	34	40.48%
Not a variable	26	30.95%

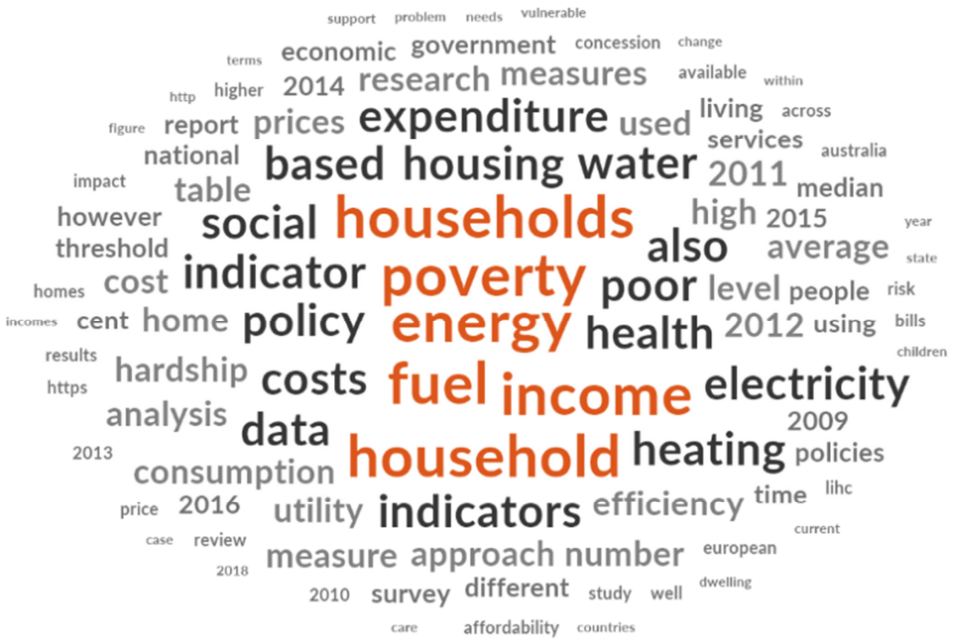
3.6 Key themes

Health impact was mentioned in 94.05% of the publications (Table 6), followed by food issues (85.71% of the publications). The ten most frequent exact words containing four or more letters were (descending order): energy, poverty, fuel, households, income, household, health, policy, poor, and costs (Figure 1). Words above 0.5% weighted percentage in the total text are shown in orange, those between 0.49-0.21% are shown in black, and words below 0.20% are shown in grey.

TABLE 6
Frequency of selected themes

Topics	Number of publications	Percentage of total
Health	79	94.05%
Food	72	85.71%
Tenure	71	84.52%
Children	71	84.52%
Elderly	69	82.14%

FIGURE 1
100 most frequent exact words containing four or more letters



4. DISCUSSION

4.1 Influence of the UK and the EU

Fifty-two publications (61.90%) of the selected literature analysed and discussed fuel poverty in European countries. The UK has viewed fuel poverty as a social, public health and climate change issue for decades, and it is the place of origin for the term (Healy and Clinch 2002). The country is still the primary reference in fuel poverty research and interventions (Primc, Dominko, and Slabe-Erker 2021; Mahoney, Gouveia, and Palma 2020), leading by a total of eighteen publications of a total of eighty-four which were selected for this study (21.43%).

England used the 10% indicator from 2001 to 2013, being substituted by the LIHC (Thomson, Snell, and Liddell 2016), which was taken over by the Low Income Low Energy Efficiency Indicator (LILEE) in 2019 (Department for Business Energy & Industrial Strategy 2021). Northern Ireland, Wales, and Scotland maintained indicators based on 10%, and those are still being used by the time this manuscript was written (Welsh Government 2021; Scottish Government n.d.; Department for Communities n.d.). However, each devolved government has its own specifications, such as Scotland using MIS and considering a 20% threshold as a condition of extreme fuel poverty (Hinson and Bolton 2021).

Other than the UK, the only European countries that have official indicators for fuel poverty are: France (six publications) (Ministère de la Transition écologique 2023), Spain (three publications) (Ministerio para la Transición Ecológica 2019), Ireland (Government of Ireland 2021), Cyprus (Ministry of Energy 2013), and Slovakia (National Council of the Slovak Re-

public 2012). The discussions on domestic fuel affordability and access have been present in these countries and the EU since the early 2000s (Thomson, Snell, and Liddell 2016).

In Oceania, Australia (twelve publications) does not have an official indicator for fuel poverty (also being called energy poverty, energy hardship, or even energy stress), and research commonly utilises data from the Household, Income and Labour Dynamics in Australia combined with objective and subjective variables to determine the prevalence of the issue (Australian Housing and Urban Research Institute 2021; Awaworyi Churchill, Smyth, and Farrell 2020; Farrell and Fry 2021). However, in New Zealand (four publications), the Ministry of Business, Innovation and Employment adopted a definition and indicators for energy hardship in 2022 (Ministry of Business Innovation & Employment 2021, 2022a, 2022b).

The USA was present in many studies (twelve publications), often discussing health issues and ethnic inequalities (Hernandez 2016; Lewis, Hernandez, and Geronimus 2019; Hernandez and Siegel 2019). Still, the country does not have an official indicators of fuel poverty (Bednar and Reames 2020). Other countries present in the selected publications were Bangladesh (one publication) and Japan (one publication), both not having official metrics for the condition.

4.2 Defining and measuring fuel poverty: biases and priorities

4.2.1 The 10% indicator

The 10% indicator was present in 59.52% of all publications selected in this study, having its roots in Boardman's 1991 publication, which was based on the excessive energy expenditure of English households with incomes in the three lowest deciles in 1988 (Boardman 1991). Boardman was responsible for drawing attention to poor housing quality as the main cause of fuel poverty, highlighting the importance of investing in energy efficiency to reduce required energy expenditure – meaning that homes would be warm without spending much money (Boardman 1991).

The main advantage of using the 10% indicator is being easy to calculate and communicate. However, it has been criticised for being outdated and region-specific (since it is based on data from England in 1988) (Liddell et al. 2012; Berry et al. 2016; Belaïd 2018). Moore (2012), Hills (2011) and others also affirmed that Boardman's indicator does not exclude households who have high incomes and those likely to be living in inefficient dwellings, having high energy needs (e.g. large households, presence of elderly or members with disabilities), and/or overusing energy (relating to wasteful habits) to surpass the 10% threshold. On the other hand, many people who are low-income and struggling with affording essential energy services may not be recognised as fuel poor because they do not reach the 10% mark (Legendre and Ricci 2015). Another issue is being oversensitive to changes in fuel prices (Romero, Linares, and López 2018).

4.2.2 The LIHC indicator

In this study, thirty-two publications (38.10%) used LIHC. Even though the LIHC indicator may seem simple, identifying those thresholds can be tricky (Romero, Linares, and López 2018): the income is calculated after subtracting housing and modelled energy costs, and it is equivalised (Hills 2012). The first threshold is 60% of the median equivalent income (Hills 2012). The second threshold is the median equivalent energy expenditure of all households (Hills 2012). Moore (2012) highlighted some issues with the LIHC, such as:

- Overlooking poorer households living in small and inefficient dwellings,
- Making fuel poverty eradication challenging to achieve for those who have low incomes and high energy expenditure, and
- Concealing the increase of fuel costs on its affordability while not reflecting fuel costs of low-income housing and its energy efficiency upgrades.

It was estimated that roughly five million English households were fuel poor in 1996, decreasing to about two million in 2001, and increasing to approximately four million in 2010, all utilising the 10% indicator (Hills 2011). However, using the LIHC changes those figures by around two million in those three years (Hills 2011), showing that changing the indicator of fuel poverty and the associated variables can drastically alter the number of affected households.

Romero, Linares, and López (2018) state that Hills's LIHC indicator has the advantage of considering not only the energy costs threshold but also an income threshold, but it is overly complex and not transparent. They argue the indicator identifies and isolates its causes and effects when analysing time series is challenging due to its double-relative nature and the difficulty in identifying which households can overcome fuel poverty by solely reducing their fuel expenditure. Moore (2012) added that its transparency issues are primarily due to equivalising energy expenditure and that setting a threshold for energy expenditure at the median (even though the energy efficiency of the housing stock is low) automatically excludes people from receiving assistance (Moore 2012). Middlemiss (2016) notes that with LIHC fuel poverty started being considered an issue that can be at most minimised, while in the past the goal was to fully eradicate it (Middlemiss 2016).

4.2.3 The subjective indicator

In the selected literature, most of publications (60.71%) included subjective fuel poverty variables. Indicators that use subjective variables through surveys and interviews have the benefit of considering the lived experience of the people struggling with fuel poverty, providing a human perspective on the issue (Mould and Baker 2017). The consistency of subjective variables can be an advantage: the same SILC questions have been asked to all the EU-28 member nations since 2010 (Thema and Vondung 2020). However, cultural and behavioural differences can create biases in their responses to subjective questions, making it difficult to do a cross-country analysis (Atsalis et al. 2016; Bosch et al. 2019). In addition, many people do not consider themselves fuel poor using subjective variables even though they could be classified as so according to objective variables, and vice-versa (Atsalis et al. 2016).

4.2.4 The MIS indicator

In this study, eleven publications (13.10%) used the MIS indicator, being based on absolute poverty (Moore 2012). Moore (2012, 22) affirms that the MIS indicator "would be readily translatable to other countries with different incomes and minimum living costs, provided that required fuel costs rather than actual fuel expenditure can be determined", which has been done successfully (Barrella, Romero, and Mariño 2022).

An advantage of MIS is seeing fuel poverty as a condition connected to other material deprivations that originates from economic poverty, allowing better understanding of the level of vulnerability of affected households (Moore 2012; Romero, Linares, and López 2018).The main challenge when using MIS is measuring the minimum income standard, which each re-

gion should define to minimise oversimplifications. In addition, choosing what to be included as essential needs is not purely objective (Moore 2012; Romero, Linares, and López 2018).

4.2.5 The AFCP indicator

Seven publications (8.05%) in the selected literature used the AFCP indicator. According to Hills (2011), this is based on modelling the energy needs of a household based, then subtracting required expenses from their income to see if it would be considered in financial poverty after energy costs. The threshold for poverty can either be the poverty line (60% of median household income) or a determined MIS (Hills 2011). For this study, all the publications that used MIS as a parameter for measuring fuel poverty were considered as using the MIS indicator.

A benefit of using AFCP is that it can include low-income households with low energy requirements as fuel poor, which is not the case for LIHC, even though those households are more vulnerable to the condition (Castaño-Rosa et al. 2019). Due to its focus on monetary variables (income, energy expenditure and a poverty threshold), AFCP minimises energy efficiency (which is a driver of fuel poverty). Consequently, this indicator makes it harder to distinguish between economic and fuel poverty itself, being a "sophisticated way of measuring the extent of poverty" (Hills 2011, 123).

4.2.6 The median and mean indicators

The 2x median and 2x mean expenditure on fuels are similar indicators found in sixteen publications (19.05%) and five (5.95%), respectively. They are based on the pioneering work by Isherwood and Hancock (1979), which was an influence on Boardman (1991) and her 10% indicator, since 10% was connected to the median household energy expenditure and income in 1988 (and being comparable to the averages from the poorest 30% in that year in England) (Hills 2011).

2x median is considered better than 2x mean since the outliers are minimised (Biermann 2016). Both the 2x median and 2x mean are traditionally based on actual energy expenditure, whereas the official 10% indicator is based on modelled energy needs (Hills 2011). Additionally, due to its relative nature, changes in energy prices are underestimated when using the two 2x indicators (Hills 2011). Not fixing the 10% threshold would be more logical and appropriate to use updated data on income and energy expenditure for current and future measures of fuel poverty (Hills 2011).

The median/2 indicator was found in five publications (5.95%). This indicator was created to see hidden fuel poverty, meaning that a household is forcefully self-rationing energy due to fuel unaffordability to economise their energy expenditure—so that spending is lower than the half of the median energy expenditure (Rademaekers et al. 2016; Meyer et al. 2018). Median/2 does not need complex calculations for the required energy needs (as it uses actual consumption) while also acknowledging that the consumption does not reflect that the needs are met (Castaño-Rosa et al. 2019; Rademaekers et al. 2016). Like MIS, hidden fuel poverty indicators are also connected to material deprivations (Meyer et al. 2018; Antepara et al. 2020; Castaño-Rosa et al. 2019).

However, the median/2 indicator only makes sense to indicate fuel poverty in low-income households, especially those who live in inefficient dwellings and/or have to choose between heating or eating (Castaño-Rosa et al. 2019; Rademaekers et al. 2016). Otherwise, households

living in extremely efficient dwellings could be categorised as fuel poor according to the median/2 indicator (Thomson and Bouzarovski 2018; Antepara et al. 2020).

4.3 Variables: identifying vulnerability

Legendre and Ricci (2015) emphasised that it is challenging to rely on a single variable to identify all households struggling with maintaining their homes at adequate temperature levels, which can be expanded to general energy use to provide essential services in a household. Variables can measure the causes or consequences of fuel poverty (Boardman 2013). Causes can be associated with income, geographic region, household structure, dwelling characteristics, fuel type used, fuel cost per unit, and water and space heater characteristics (Baudu, Charlier, and Legendre 2020; Fahmy 2011; Boardman 2013). Consequences can be behaviour and habits of household members, health conditions, and the presence of dampness, leaks and mould (Ginestet et al. 2020; McKague et al. 2016).

Of the variables highlighted in this study, income (70.24% of publications) the size of the household (51.19% of publications), and age of household members (51.19% of publications) were the most common ones. These three are objective variables that are connected to the causes of fuel poverty, helping identify vulnerable households. As for the household size, it can be used to equivalise the household's income and estimate their energy needs (Tirado Herrero 2017). Most indicators of fuel poverty are income-based (e.g. MIS, 10%, LIHC, AFCP) with 70.24% of publications using income-related variables. Some indicators rely on variables associated with economic aspects to determine risks (e.g. variables such as the ability to afford warmth), which is indirectly related to income. The age of household members is associated with the equivalisation of income and estimating energy needs (Boardman 2013).

The presence of elderly members in a household was cited in 82.14% of the selected publications, as they are associated with higher thermal energy consumption, higher health issues and vulnerability to them, lower incomes and living in under-occupied homes and are considered a vulnerable group to fuel poverty (Besagni and Borgarello 2019; Boardman 2013). The presence of children was referenced in 84.52% of the publications, as they are also more vulnerable to health conditions associated with fuel poverty, and the situation is aggravated if they live with a single parent, being associated with lower-income households (Boardman 2013).

Boardman (2013) also noted that considering income before or after housing affect fuel poverty numbers, as the former will be biased in favour of (mostly homeowning) pensioners, whereas the latter sets households with children as the priority. Equivalisation of income (present in 47.62% of publications) will favour larger households. However, using unequivalised income (51.19% of publications) does not acknowledge that larger households have higher non-fuel expenses, leaving them with less money to afford their energy needs (which are already higher) (Fahmy 2011; Burlinson, Giulietti, and Battisti 2018).

Other objective variables highlighted in the selected publications that relate to the causes of fuel poverty and are connected to household characteristics are employment status (19.05% of publications) and home ownership or rental (7.14% of publications). The unemployed and the retired have lower incomes and spend more time at home, resulting in higher energy needs (Belaïd 2018; Chaton and Gouraud 2020; Boardman 2013). As a topic, tenure was mentioned in 84.52% of publications, as renters are over-represented as fuel poor households due to less disposable income after housing costs (Belaïd 2018; Gouveia et al. 2022), poor energy efficiency (Boardman 2013), and inability to retrofit the dwellings due to not being the property

owners nor having the financial means, even though they are the ones who pay the energy bills and are directly affected by fuel poverty (Barton 2014).

Fuel prices (26.19%), size of dwelling (30.95%), dwelling type (23.81%), and age of dwelling (19.05%) are objective variables relating to the causes of fuel poverty, which are also used to determine energy needs and convert it into required expenditure.

The two subjective variables analysed in this study can be summarised as the ability to maintain the home warm (44.05% of publications) and arrears on utility/energy bills (44.05% of publications), all relating to consequences of fuel poverty. They are a reference to the popular EU-SILC variables (Thema and Vondung 2020). Even though subjective variables highlight households' difficulties concealed by using expenditure-based indicators of fuel poverty, some people may minimise their struggles due to feelings such as embarrassment and pride associated with their cultural background (Waitt and Harada 2019; McKague et al. 2016).

Food was a topic mentioned in seventy-two materials (85.71%) studied in the selected publications, showing a strong connection between food insecurity and fuel poverty, known as the heat or eat dilemma. Some households actively (and dangerously) reduce energy consumption to afford food, while others cut back on food (especially fruits and vegetables) to afford their energy bills (Llorca, Rodriguez-Alvarez, and Jamasb 2020; McKague et al. 2016). Limited income is a cause of fuel poverty, whereas the coping mechanisms mentioned are consequences. Variables of fuel poverty or its risk explicitly relating to food (e.g. EU-SILC question about the ability "to afford a meal with meat, chicken, fish or vegetarian equivalent every second day" (Bosch et al. 2019, 1386)) can be beneficial for finding vulnerable households.

Food insecurity also relates to fuel poverty as disconnected (including self-disconnected) households lose their ability to use their appliances, with spoiled food being a health hazard and undesired expense to already vulnerable households (McKenzie 2013). Additionally, food costs must also be part of the MIS calculation (Moore 2012).

The remaining variables analysed in this study also relate to the consequences of fuel poverty but are objective: damp walls/floor/foundation (22.62% of publications), leaking roof (15.48% of publications), and rot on window frames/floor (14.29%). These variables relate to the dwelling and are strongly connected to the presence of mould due to poor housing quality (Ginestet et al. 2020).

Health was mentioned in seventy-nine publications from the selected literature (94.05%), as being in fuel poverty can create health issues, aggravate existing ones, or even cause death due to issues such as inappropriate indoor temperatures, presence of mould, household members unable to use electricity-powered life support equipment, and negatively impacting mental health and wellbeing of household members (Teli et al. 2015; Ginestet et al. 2020; Simshauser, Nelson, and Doan 2011; Awaworyi Churchill, Smyth, and Farrell 2020). These issues are even more severe in vulnerable household members who are elderly, children or have a disability or chronic illnesses, which are also associated with lower income and/or higher energy needs (Snell, Bevan, and Thomson 2015; Boardman 2013).

4.4 Estimating energy expenditure or accepting self-rationing?

Forty-two publications (50.00%) in the selected literature used actual energy expenditure as a variable, while thirty-four publications (40.48%) used required energy expenditure.

Some of the variables highlighted in the selected publications include fuel prices (26.19% of publications), size of dwelling (30.95% of publications), dwelling type (23.81% of publications), and age of dwelling (19.05% of publications). Fuel prices associated with the physical

characteristics of the dwelling (and where it is located geographically), space heating/cooling systems, and water heaters (including the type of fuel used) are part of the calculation required for energy expenditure. However, the household structure also needs to be considered.

The size of the household (51.19% of publications) and age of household members (51.19% of publications) are considered to determine the household's energy needs. The Organisation for Economic Co-operation and Development developed an equivalisation scale that is often used to equivalise energy needs: 1 consumption unit for the first adult in a household, 0.5 consumption unit for each additional person who is at least fourteen years old, and 0.3 consumption unit for each person who is younger than fourteen years old (Berry et al. 2016; Chaton and Gouraud 2020).

Employment status (19.05% of publications) is also an important factor: households with at least one member frequently staying at home (e.g. retired and unemployed) will have a different heating regime compared to all members being away from home for work or school, with the former situation usually set at sixteen hours of daily heating while nine hours is considered the standard (for the latter) (Boardman 2013). In addition, under-occupation can be considered for the heating regime: in that case, half the space of the dwelling should be heated (Boardman 2013).

Using the amount of money or energy unit (e.g. kW·h) actually consumed by the household is straightforward, being significantly easier to obtain this data than estimating the required energy needs by using household and dwelling aspects. However, this does not necessarily represent how much the household should be consuming to maintain proper temperature levels and meetings other basic energy needs (Boardman 2013, 2012).

The average energy expenses can be based on year-round data from households or only the months with increased consumption (summer and/or winter) (Waddams Price, Brazier, and Wang 2012). Moore (2012) also suggested that the monthly income associated with the seasons should also be adopted. As mentioned previously, using median values of energy expenditure instead of the mean to compare households has the advantage of being closer to the typical use by households since the mean is more affected by outliers (Moore 2012).

To avoid neglecting the issue of under-consuming energy due to self-rationing when using actual energy expenditure values, the analyst should consider including some well-established subjective variables or others that can measure energy practices and coping mechanisms of households can be beneficial (McKague et al. 2016). Unfortunately, subjective variables relating to energy behaviour are less likely to be representative of a whole region. Using the median/2 indicator in addition to questions about the dwelling quality and household income can also help in those situations when the required energy values are not available (Thomson and Bouzarovski 2018; Barrella et al. 2022). Other supporting indicators (e.g. excess winter mortality) can be used as well (Palma and Gouveia 2022).

Even though self-rationing is a known phenomenon, using the actual energy expenditure was found to be more common than required energy expenditure, probably due to the former data being easier to be obtained rather than calculating the latter. All indicators and variables of fuel poverty itself or its vulnerability have strengths and weaknesses, focusing on specific facets of the issue. As Boardman (2013, 34) stated, "the method chosen and the groups prioritized are a political, not academic, decision."

5. CONCLUSION

This study is a systematic literature review of relevant publications on fuel poverty to analyse their key indicators and variables, discussing patterns in the themes explored in those publications and the reasoning behind their chosen methods for measuring fuel poverty. Findings showed that the UK and EU predominate fuel poverty research and policies, with the subjective, the 10%, and the LIHC indicators being the prevalent ones. Variables relating to the household composition and structure were the most frequent, with fuel poverty being considered a social and health issue.

Novel indicators are also encouraged by the authors to suit the specific needs of each case. The authors propose a combination of different household, dwelling, and economic variables to see the multiple facets of fuel poverty. Indicators and variables that can adapt to future changes and identify the severity of fuel poverty should also be prioritised.

This study intends to help researchers, policymakers, and other groups involved in mitigating fuel poverty choose variables that prioritise the most underprivileged groups, understanding that their choices can overlook certain essential aspects of the issue. The authors suggest that future research and interventions use a combination of both objective and subjective variables to create a more holistic view of fuel poverty as it can minimise biases against certain affected groups.

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APPENDIX A

Publications used in this systematic literature review

Author	Paper	Type
Ali et al (2015)	Responding to consumers' financial hardship: An evaluation of the legal frameworks and company policies	Journal article
Awaworyi Churchill et al (2020)	Fuel poverty and subjective wellbeing	Journal article
Azpitarte et al (2015)	Fuel poverty, household income and energy spending: an empirical analysis for Australia using HILDA data	Report
Barnes et al (2011)	Energy poverty in rural Bangladesh	Journal article
Bednar & Reames (2020)	Recognition of and response to energy poverty in the United States	Journal article
Berry et al (2016)	Investigating fuel poverty in the transport sector: Toward a composite indicator of vulnerability	Journal article
Betto et al (2020)	A new measure of Italian hidden energy poverty	Journal article
Bilodeau et al (2017)	Household material hardship in families of children post-chemotherapy	Journal article
Bona et al (2015)	Trajectory of Material Hardship and income Poverty in Families of Children Undergoing Chemotherapy: A Prospective Cohort Study	Journal article
Bona et al (2015)	Prevalence and Impact of Financial Hardship among New England Pediatric Stem Cell Transplantation Families	Journal article
Bourova et al (2017)	Reporting on Hardship Practice in the Consumer Credit and Energy Sectors: An Analysis	Journal article
Bouzarovski & Tirado Herrero (2017)	Geographies of injustice: the socio-spatial determinants of energy poverty in Poland, the Czech Republic and Hungary	Journal article
Bouzarovski (2013)	Energy poverty in the European Union: landscapes of vulnerability	Journal article
Bouzarovski et al (2012)	Energy poverty policies in the EU: A critical perspective	Journal article
Brabo-Catala et al (2022)	Fuel Poverty or Energy Hardship? Analysing the literature, the proposed official definition, and the views of experts in Aotearoa New Zealand	Journal article
Burke et al (2015)	Household energy use: Consumption and expenditure patterns 1993-2012	Report
Burlinson et al (2018)	The elephant in the energy room: Establishing the nexus between housing poverty and fuel poverty	Journal article
Burlinson et al (2021)	Fuel poverty and financial distress	Journal article
Castaño-Rosa & Okushima (2021)	Prevalence of energy poverty in Japan: A comprehensive analysis of energy poverty vulnerabilities	Journal article
Castaño-Rosa et al (2019)	Towards a multiple-indicator approach to energy poverty in the European Union: A review	Journal article
Chan (2015)	Rethinking water and energy affordability in Australia: an analysis of the efficiency, effectiveness and equity of current policy	PhD thesis
Charlier & Legendre (2019)	A Multidimensional Approach to Measuring Fuel Poverty	Journal article
Charlier & Legendre (2021)	Fuel poverty in industrialized countries: Definition, measures and policy implications a review	Journal article
Che et al (2021)	Assessing global energy poverty: An integrated approach	Journal article
Cong et al (2022)	Unveiling hidden energy poverty using the energy equity gap	Journal article
Day et al (2016)	Conceptualising energy use and energy poverty using a capabilities framework	Journal article
Deller et al (2021)	Energy poverty indicators: Inconsistencies, implications and where next?	Journal article
Dodd & Nelson (2022)	Australian household adoption of solar photovoltaics: A comparative study of hardship and non-hardship customers	Journal article
Fabbri (2015)	Building and fuel poverty, an index to measure fuel poverty: An Italian case study	Journal article
Fahmy (2011)	The definition and measurement of fuel poverty	Briefing paper
Fahmy et al (2011)	Predicting fuel poverty at a small-area level in England	Journal article
Faiella & Lavecchia (2021)	Energy poverty. How can you fight it, if you can't measure it?	Journal article
Fernandez et al (2018)	Dual Food and Energy Hardship and Associated Child Behavior Problems	Journal article
Fizaine & Kahouli (2018)	On the power of indicators: how the choice of fuel poverty indicator affects the identification of the target population	Journal article

Author	Paper	Type
Frank et al (2010)	Cumulative hardship and wellness of low-income, young children: multisite surveillance study	Journal article
Halkos & Gkampoura (2021)	Evaluating the effect of economic crisis on energy poverty in Europe	Journal article
Heindl (2015)	Measuring Fuel Poverty: General Considerations and Application to German Household Data	Journal article
Hernandez & Siegel (2019)	Energy insecurity and its ill health effects: A community perspective on the energy-health nexus in New York City	Journal article
Hernandez (2016)	Understanding 'energy insecurity' and why it matters to health	Journal article
Hernandez et al (2016)	Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States	Journal article
Hills (2011)	Fuel poverty: the problem and its measurement	Report
Hills (2012)	Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review	Report
Imbert et al (2016)	Same but different: On the applicability of fuel poverty indicators across countries—Insights from France	Journal article
Judson & Zirakbash (2022)	Investigating the potential of solar energy for low-income communities in Australia to reduce hardship, debt and inequality	Journal article
Kahouli (2020)	An economic approach to the study of the relationship between housing hazards and health: The case of residential fuel poverty in France	Journal article
Kose (2019)	Energy poverty and health: the Turkish case	Journal article
Legendre & Ricci (2015)	Measuring fuel poverty in France: Which households are the most fuel vulnerable?	Journal article
Lewis et al (2020)	Energy efficiency as energy justice: addressing racial inequities through investments in people and places	Journal article
Liddell et al (2011)	Defining fuel poverty in Northern Ireland: A preliminary review	Report
Liddell et al (2012)	Measuring and monitoring fuel poverty in the UK: National and regional perspectives	Journal article
Lloyd (2006)	Fuel poverty in New Zealand	Journal article
März (2018)	Assessing the fuel poverty vulnerability of urban neighbourhoods using aspatial multi-criteria decision analysis for the German city of Oberhausen	Journal article
Maxim et al (2016)	Implications and Measurement of Energy Poverty across the European Union	Journal article
Meyer et al (2018)	Capturing the multifaceted nature of energy poverty: Lessons from Belgium	Journal article
Middlemiss (2017)	A critical analysis of the new politics of fuel poverty in England	Journal article
Moore (2012)	Definitions of fuel poverty: Implications for policy	Journal article
Morrison et al (2008)	Fuel poverty in Scotland: Refining spatial resolution in the Scottish Fuel Poverty Indicator using a GIS-based multiple risk index	Journal article
Mould & Baker (2017)	Documenting fuel poverty from the householders' perspective	Journal article
Nelson et al (2019)	The drivers of energy-related financial hardship in Australia–understanding the role of income, consumption and housing	Journal article
O'Sullivan & Viggers (2021)	Six ways to help fix energy hardship in New Zealand	Journal article
O'Sullivan et al (2014)	The influence of electricity prepayment meter use on household energy behaviour	Journal article
Oliveras et al (2020)	The association of energy poverty with health, health care utilisation and medication use in southern Europe	Journal article
Papada & Kaliampakos (2016)	Measuring energy poverty in Greece	Journal article
Phimister et al (2015)	The Dynamics of Energy Poverty: Evidence from Spain	Journal article
Rademaekers et al (2016)	Selecting Indicators to Measure Energy Poverty	Report
Roberts et al (2015)	Fuel poverty in the UK: Is there a difference between rural and urban areas?	Journal article
Robinson et al (2018)	'Getting the measure of fuel poverty': The geography of fuel poverty indicators in England	Journal article
Romero et al (2018)	The policy implications of energy poverty indicators	Journal article
Schuessler (2014)	Energy Poverty Indicators: Conceptual Issues—Part I: The Ten-Percent-Rule and Double Median/Mean Indicators	Discussion paper

Author	Paper	Type
Siksnelyte-Butkiene et al (2021)	Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity	Journal article
Simcock et al (2016)	Fuel poverty in the UK: Beyond heating	Journal article
Simhauser & Nelson (2012)	The energy market death spiral-rethinking customer hardship	Working paper
Simhauser & Nelson (2014)	The Consequences of Retail Electricity Price Rises: Rethinking Customer Hardship	Journal article
Simoes et al (2016)	Mapping Fuel Poverty in Portugal	Journal article
Sokolowski et al (2020)	A multidimensional index to measure energy poverty: the Polish case	Journal article
Thomson & Bouzarovksi (2019)	Addressing Energy Poverty in the European Union: State of Play and Action	Report
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Thomson et al (2016)	Fuel poverty in the European Union: a concept in need of definition?	Journal article
Thomson et al (2017)	Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data	Journal article
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Waddams Price et al (2012)	Objective and subjective measures of fuel poverty	Journal article
Walker et al (2014)	Estimating fuel poverty at household level: An integrated approach	Journal article
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