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MEASURING ENERGY POVERTY IN POLAND WITH THE MULTIDIMENSIONAL ENERGY POVERTY INDEX

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Abstract

Energy poverty is a complex problem that is generally caused by having a low income, having high energy costs, and/or living in a home with low energy efficiency. Various indicators capture these factors, but there is no consensus among researchers on which is the best one, or on how to combine them. Thus, poverty mapping and policy planning would benefit from having access to a unitary index of poverty. We have created a multidimensional energy poverty index using the methodology proposed by Alkire and Foster (2008). The index accounts for five dimensions of energy deprivation: two objective indicators of "low income, high costs" and "high share of energy expenditure in income", as well as three subjective indicators of "inability to keep the home adequately warm", "presence of leaks, damp, or rot" and "difficulties paying utility bills". We define households as poor if at least two forms of deprivation are present. We apply our index to Poland using Household Budget Survey data. We find that in 2017, 10% of households in Poland suffered from multidimensional energy poverty, and that about half of these households were also income-poor. Households living in buildings built before 1946, households living in rural areas, and households that were dependent on retirement and disability pensions or on unearned sources of income were at especially high risk of energy poverty.

Keywords: energy poverty, multidimensional poverty index, Alkire-Foster method

JEL: I32, R29, Q40

• This paper uses Statistics Poland data. Statistics Poland has no responsibility for the results and conclusions, which are those of the authors. The usual disclaimers apply. All errors are ours.

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1. Introduction

Energy poverty occurs when a household is unable to afford the energy needed to provide its members with adequate warmth, cooling, lighting, and appliance use. It generally results from three factors: a low household income, high energy costs, and the low energy efficiency of a dwelling. The issue of energy poverty has gained recognition among researchers and policy-makers since the seminal work of Boardman (1991).

The measurement of energy poverty has two main aims. First, the identification of energy-poor households should enable the efficient implementation of support measures. Second, the measurement should capture the relevant features of deprivation. Ideally, energy poverty metrics would include both quantitative and qualitative components that ensure comprehensive coverage while minimizing biases in the representations of outcomes. Indeed, the EU Poverty Observatory monitors energy poverty using four primary indicators, including two objective and two self-reported measures, and a wide range of secondary indicators (EPOV, 2018). To monitor energy poverty in Poland, Sokołowski et al. (2019) recommended five indicators that capture key dimensions of energy poverty: high required energy costs and low income, high actual energy expenditure, inability to adequately heat the building, housing faults, and inability to pay utility bills. These indicators are analogous to those recommended by EPOV (2018), and take advantage of detailed expenditure data available for Poland.

Using a group of objective and subjective indicators has advantages: it accounts for a diversity of concepts of energy poverty, and presents a broader picture than any single indicator could. However, it also has disadvantages, especially if the indicators are used as the basis for social policies, and different indicators show different results. Indeed, this is the case in Poland: the share of energy-poor households ranges from 2.2% to 18% (in 2017), depending on the indicator applied (Sokołowski et al., 2019). Furthermore, different indicators identify different subpopulations as those at highest risk in Poland. For instance, the objective indicators show that inhabitants of detached homes are at highest risk of energy poverty, while the subjective indicators show that inhabitants of old multifamily buildings are at highest risk of energy poverty. Such discrepancies pose obvious challenges for policy-makers.

In this article, we propose a multidimensional index that accounts for the multi-faceted nature of energy poverty, but that results in a single indicator that can be used for poverty mapping and policy planning. We combine objective and subjective indicators (five in total), and assign an equal weight to each indicator. We address the key drawback of using single indicators only: namely, that conflicting interpretations and results inevitably arise. At the same time, we provide a single index of multidimensional poverty at the household level for which the interpretation is clear: i.e., a household is considered energy-poor if it experiences at least two forms of deprivation. We base our approach on the concept of the multidimensional poverty index developed by Alkire and Foster (2008). We apply our methodology to Poland, taking advantage of data from the Polish Household Budget Survey (HBS). The HBS is a large-scale survey that includes data on income, energy spending, and subjective assessments of living conditions, as well as on dwelling characteristics.

Previous attempts to combine various indicators in a single index of energy poverty were based on calculating a compound index, or a weighted mean of the scales of different deprivation dimensions (e.g., Thomson and Snell, 2013). The energy poverty index developed by Bouzarovski and Tirado Herrero (2015) is an example of a weighted mean, which takes into account the percent scale of households facing problems with utility bills (weighted 0.5),

inadequate living conditions, and insufficient thermal comfort (each with a weight of 0.25).[1] Although useful for making comparisons across EU countries, such a compound index cannot be applied to measure the incidence of poverty at the household level. Moreover, the outcome of a compound index may not reflect the differences in the distribution of deprivation forms across households. If, for example, three households are identified by one indicator each in one case, and one household is identified by three different indicators in another case, both cases will have the same compound index values, even though the underlying experiences of energy poverty are very different. By contrast, a multidimensional approach will generate vastly different results.

The concept of multidimensional inequality and poverty has been widely applied to studies of poverty and living conditions since the seminal works of Sen (1976), Kolm (1977), and Atkinson and Bourguignon (1982), among others[2]. However, to the best of our knowledge, the Alkire-Foster method has not previously been used to measure energy poverty in Europe. While Nussbaumer et al. (2011), and Sadath and Acharya (2017) applied this method to measure energy poverty in developing countries, due to data limitations, they were able to measure self-reported forms of deprivation. Our paper is the first to combine objective and subjective indicators of energy deprivation.

This article contributes to the improvement of the measurement of energy poverty by assessing not only the scale, but the incidence of multiple energy poverty dimensions in a given household. This approach can be applied in other countries, although the selection of dimensions of deprivation forms and indicators will differ depending on the country-specific context. Therefore, the multidimensional index could be used not only to monitor and plan national support measures and policies, but to compare the scale of energy poverty across countries.

The article is organised as follows. In the second section, we outline our methodology and data. In the third section, we present and discuss the results. The fourth section concludes. The appendix presents additional methodological details on how particular indicators were constructed.

2. Methodology and data

We calculate the multidimensional energy poverty index following the methodology developed by Alkire and Foster (2008) and Alkire and Apablaza (2016). For every household *I*, we set a deprivation matrix assigning a value of one if the household is deprived in a given dimension $\in D$, where D is the set of dimensions; and a value of zero if it is not. Then, for each household, we add the positive entries, weighting each dimension with w_d, where w_d sum up to one. This weighted sum c_i is the deprivation score; or in other words, the weighted share of deprivation forms suffered by the household. A household is identified as poor if its weighted deprivation score c_i is higher than the poverty cut-off, *k*. Finally, we calculate the headcount ratio (*H*) as the proportion of households that are multi-dimensionally poor. We use the headcount ratio to identify the scale of multidimensional energy poverty.

[1] The energy poverty index is based on the EU-SILC data by Eurostat.

[2] A detailed literature survey on the mentioned methods is due to Jenkins and Van Kerm (2009).

We use five indicators to construct the multidimensional index of energy poverty. "Low income, high costs" (hereafter, LIHC) and "high share of energy expenditure in income" (high actual costs) are considered objective indicators. They are calculated on the basis of the information on the households' income and energy expenditures. "Inability to keep the home adequately warm" (not warm enough), "presence of leaks, damp, or rot" (housing faults), and "inability to pay utility bills" (bills difficulties) are self-reported indicators. These five indicators have been recommended by the EU Energy Poverty Observatory, and have been shown to be the most suitable measures of country-specific features of energy poverty in Poland (Sokołowski et al., 2018). The methodology of each indicator is described in detail in the appendix.

We treat each type of deprivation as equally important and therefore assign an equal weight to each dimension (w_d = 1/5). This approach is commonly used in studies of multidimensional poverty (Alkire and Apablza, 2016). It ensures the replicability of the calculations. We set the multidimensional poverty cut-off point at the level of $k \geq 0.4$, which means that households with at least two out of five forms of deprivation will be identified as energy-poor.

Table 1. Unitary dimensions of energy poverty

Indicator	Abbreviation	Household is deprived if:
Low income, high cost	LIHC	Household has high required energy costs (above the national median level) and low income. The required energy costs are the expenditures needed to meet the energy needs given the household's characteristics. The low income threshold is below the 30th percentile of equivalent income, and is below the individual income threshold, which takes into account the housing situation.
High share of energy expenditure in income	High actual cost	Household spends a high share of its income on actual energy costs (more than twice the national median level "2M").
Inability to keep the home adequately warm	Not warm enough	Household members report that the dwelling is not warm enough in the winter.
Presence of leaks, damp, or rot	Housing faults	Household members live in a dwelling with a leaking roof; damp walls, floors, or foundations; or rot in the window frames or floors.
Inability to pay utility bills	Bills difficulties	Household members experience problems paying their utility bills on time.

Note: A detailed description of the construction of the indicators is presented in the appendix.

Source: Own elaboration.

We use Polish Household Budget Survey (HBS) data for 2017. The HBS is a nationwide representative survey carried out by the Polish statistical office (Statistics Poland). The questionnaire covers all of the households' revenues and expenditures, as well as the respondents' subjective assessments of their material situation and their housing conditions. Therefore, the HBS allows us to calculate all five dimensions of energy poverty.

Households are the unit of analysis, and all five indicators are defined at the household level. We estimate the incidence of energy poverty as the share of households identified as energy-poor. We also calculate the population shares in order to ensure the comparability of these indicators with standard income poverty indicators. The number of observations in the 2017 database is 36,665 of households (97,434 persons). After dropping observations with missing data, the sample consists of 35,980 households (95,621 persons). We use

survey weights that are representative at the household level (number of persons in the household and urban/rural area). After reducing the sample, we recalibrate the weights to make them representative at the individual level (age and sex), following Myck and Najsztub (2015).

3. Results

3.1. Multidimensional energy poverty index – composition by forms of deprivation

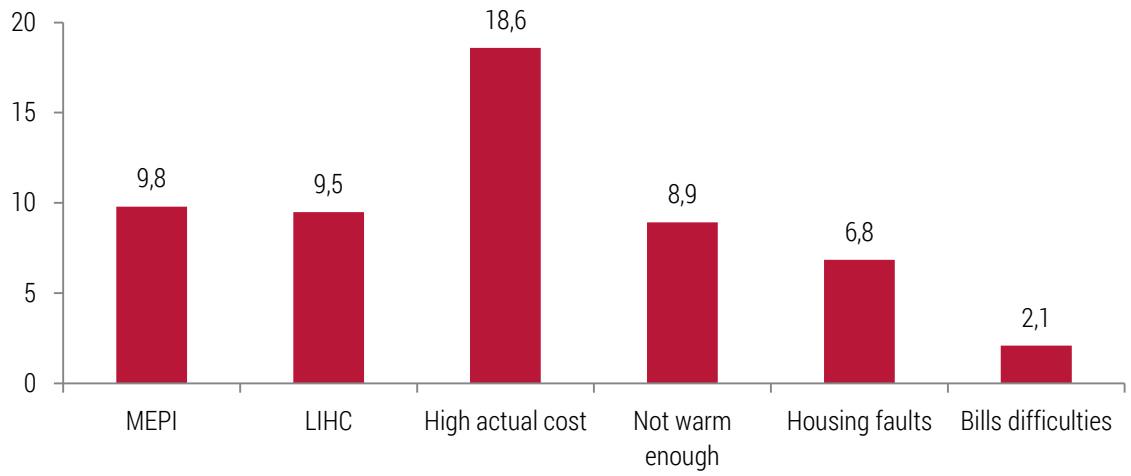
Our findings indicate that 1.33 million out of 13.57 million households (9.8%) in Poland are energy-poor in the multidimensional sense (in 2017). In population terms, 3.35 million people out of the 38 million people living in Poland (8.8%) are affected. The vast majority (1.06 million, 7.8% of households) of households identified as poor in the multidimensional sense are affected by exactly two forms of deprivation (Table 2). The number of households affected by three of more forms of deprivation is much lower (314 thousand, or 2% of households). On the other hand, the results also show that one in four households in Poland are deprived in exactly one dimension, while two in three households are not affected by energy poverty at all.

Table 2. Coincidence of single dimensions of energy poverty

Number of dimensions	Frequency (thousands of households)	Cumulative frequency (thousands of households)	Percentage of households	Cumulative percentage
5	2	2	0.0	0.0
4	42	44	0.3	0.3
3	224	268	1.7	2.0
2	1064	1332	7.8	9.8
1	3257	4589	24.0	33.8
0	8983	13572	66.2	100.0

Source: Own calculations based on the Household Budget Survey data, 2017.

Figure 1. Energy poverty rate according to the multi-dimensional and single indicators (percent of households)



Source: Own calculations based on the Household Budget Survey data, 2017.

The share of households affected by multidimensional energy poverty in Poland (9.8%) is comparable to the shares affected by poverty as defined by the LIHC and the "not warm enough" indicators. The "high actual costs" indicator is associated with a high incidence of energy poverty, of almost 20%. At the other end of the spectrum is the "bills difficulties" indicator, which identifies only 2% of households as energy-poor. In comparison to the single indicators, the poverty rate according to the multidimensional index seems to be neither over- nor underestimated.

Table 3. Energy poor households, by dimensions of the poverty

Dimensions of the energy poverty					Number of households (thousands)	Share among energy-poor (%)
Low income, high cost	High actual cost	Bills difficulties	Housing faults	Not warm enough		
*	*				418	31.4
			*	*	211	15.8
	*			*	152	11.4
	*		*		96	7.2
	*		*	*	74	5.6
*				*	54	4.1
	*	*			45	3.4
*			*		38	2.9
*	*			*	32	2.4
		*	*	*	26	1.9
*	*		*		24	1.8
*			*	*	23	1.7
*	*		*	*	20	1.5
*	*	*			18	1.4
		*		*	17	1.3
		*	*		17	1.3
*		*			15	1.1
	*	*	*	*	11	0.8
	*	*	*		10	0.7
*		*	*	*	8	0.6
	*	*		*	8	0.6
*		*	*		6	0.4
*		*		*	4	0.3
*	*	*	*	*	2	0.2
*	*	*		*	2	0.1
*	*	*	*		2	0.1
					1332	**100.0**

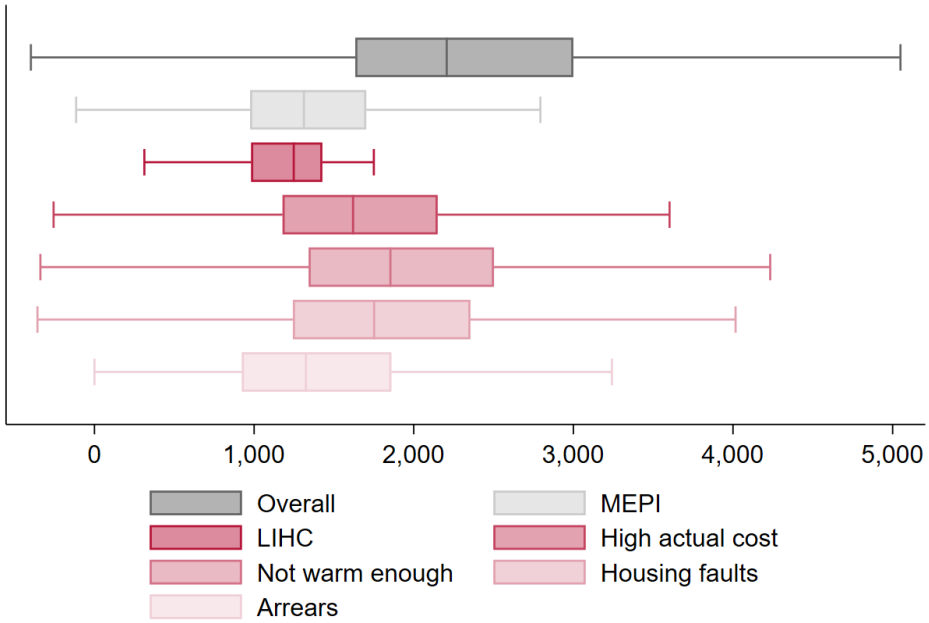
*Note: * indicates the occurrence of a specific energy poverty dimension.*
Source: Own calculations based on the Household Budget Survey data, 2017.

Among the energy-poor households, the combination of the "low income, high costs" and "high actual cost" forms of deprivation is the most common (31% of poor households, according to the multidimensional index), followed by the combination of "leaks, damp, or rot" and "not warm enough" (16%, see Table 3). The former subgroup is identified as energy-poor based on the overlap of two objective indicators, while the latter is identified based on the overlap of two subjective indicators. Although the nature of energy poverty among these groups is different, we argue that the use of a multidimensional index makes the identification more credible than it would have been if single indicators had been used (which may be affected by measurement errors or spurious self-assessments). The 48% of households identified as energy-poor in a multidimensional sense exhibited some objective and some subjective forms of deprivation. The ability to identify households that are affected by both expenditure-based and subjective indicators of energy poverty is a desirable feature of the multidimensional approach.

3.2. Multidimensional energy poverty and household incomes

The equivalised incomes of energy-poor households are relatively low in comparison to the overall equivalised income distribution in Poland. This finding is especially clear in the multidimensional index, which shows that for the LIHC and the "bills difficulties" indicators, the median equivalised income among these groups is visibly lower than the 25th percentile of the overall equivalised income distribution (Figure 2). The incomes of households that are identified as poor according to the "high actual costs", "not warm enough", and "housing faults" indicators are higher. Some households that belong to these groups have incomes above the 75th percentile of the overall distribution. However, these households are not classified as poor according to the multidimensional indicator, which is a key advantage. On the one hand, it is important to identify energy-poor households that are not income-poor, and our energy poverty indicators do so. On the other hand, it is important to avoid capturing households with "excessively high" incomes, who may be able to overcome the difficulties associated with having high energy needs on their own.

Figure 2. Equivalised income of households – overall and for energy-poor households (multi-dimensionally and according to single indicators)

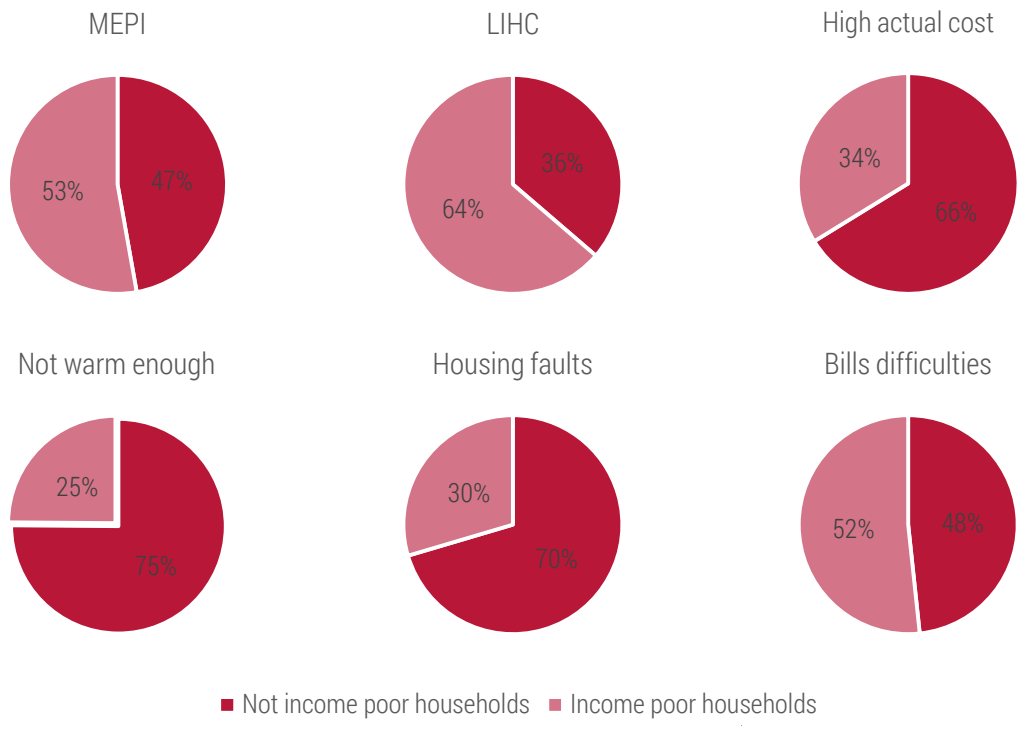


Note: Boxplots identify the median, the first and the third quartile, and the minimum and the maximum of equivalised income in PLN. Outside values are excluded.

Source: Own calculations based on the Household Budget Survey data, 2017.

Slightly more than a half (53%) of the households identified as energy-poor according to the MEPI are also income-poor. The share of income-poor households is similar for the "bills difficulties" indicator, higher for the LIHC indicator, and lower for the other single energy poverty indicators (Figure 3). These disparities between income and energy poverty are likely to be of special interest to policy-makers, as they stem from the lack of dedicated support for energy-poor households in Poland (Rutkowski et al., 2018). Energy-poor households can expect support only if they suffer from income poverty and receive forms of social assistance that are reserved for the poorest individuals.

Figure 3. Income poverty among energy-poor households (multi-dimensionally and according to single indicators)



Source: Own calculations based on the Household Budget Survey data, 2017.

The multidimensional energy poverty rate is much higher among households living on non-earned sources of income than it is among any other socioeconomic group (Figure 4). Farmers, retirees, and pensioners also experience high rates of multidimensional poverty. However, there are differences between these groups in the specificity of energy poverty. Recipients of non-earned income who have low incomes are most likely to be affected by the "high expenditure" and the self-reported forms of deprivation. Retirees and pensioners are also among those most likely to spend a high share of their income on energy. While farmers are most often affected by the objective forms of deprivation, especially the "low income, high costs" indicator, the incidence of subjective forms of deprivation among these households is quite low. The construction of the multidimensional index makes the energy poverty level ascribed to farmers more reliable. The risk of energy poverty among farmers can be overestimated when based on the expenditure-based indicators, since farmers can experience irregularities in their income due to seasonal fluctuations. Thus, the incomes of farmers are particularly likely to be affected by the measurements applied. In particular, the energy poverty of farmers may be overestimated by the "low income, high costs" and "high expenditure" indicators. The application of the multidimensional index alleviates this effect.

Retirees and pensioners, recipients of non-earned income sources, and blue-collar workers constitute the three most numerous groups among the energy-poor, according to the MEPI (Table 4), with 78% of all energy-poor households belonging to one of these three groups. Retirees and pensioners and recipients of non-earned income sources are overrepresented among the energy-poor in comparison to their shares in the total population. Farmers are also overrepresented among the multi-dimensionally poor. The opposite pattern is observed for blue-collar workers, white-collar workers, and the self-employed. The overlap between income and multidimensional energy poverty is most pronounced among farmers (83% of energy-poor farmers are also income-poor) and

recipients of non-earned income sources (79%), while it is the smallest among blue-collar workers (31%) and white-collar workers (37%).

Figure 4. Multidimensional energy poverty index and single dimensions of energy poverty, by main source of household income (percent of households).

Source: Own calculations based on the Household Budget Survey data, 2017.

Table 1. Structure of energy-poor households by main income source

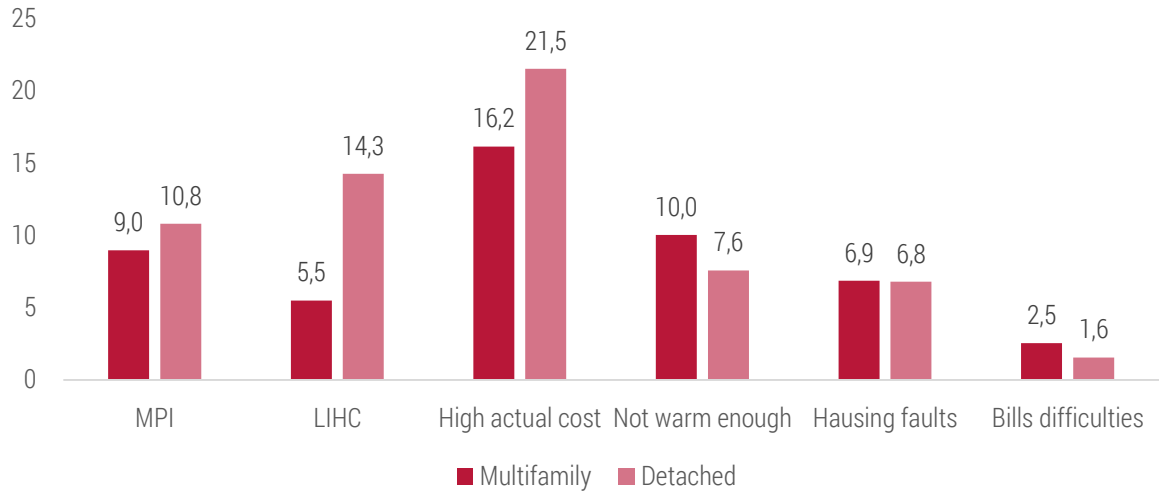
Main source of income	Energy-poor households		Energy- and income-poor households		All households	
	Number of households (thousands)	Share among energy-poor (%)	Number of households (thousands)	Share among energy-poor (%)	Number of households (thousands)	Share among all households (%)
Blue-collar workers	309	23.2%	95	7.1%	3 428	25.3%
White-collar workers	137	10.3%	51	3.8%	3 651	26.9%
Farmers	104	7.8%	86	6.5%	567	4.2%
Self-employed	48	3.6%	22	1.7%	951	7.0%
Retirees and pensioners	593	44.5%	340	25.5%	4 522	33.3%
Recipients of other non-earned income sources	140	10.5%	110	8.3%	452	3.3%
Total	1 332	100%	704	52.9%	13 571	100%

Source: Own calculations based on the Household Budget Survey data, 2017.

3.3. Multidimensional energy poverty and building characteristics

The risk of energy poverty in Poland is strongly related to the characteristics of dwellings. According to the MEPI, energy poverty is more common among households living in detached houses than among households living in multifamily buildings (Figure 5). This difference is driven by the results of the expenditure-based indicators, which show a much higher risk of energy poverty among households living in detached houses. This finding can in turn be related to the fact that in Poland, the dwelling areas in detached houses are much larger than the dwelling areas in multifamily buildings (Lewandowski et al., 2018), which translates into higher heating costs. On the other hand, the subjective indicators show that households living in multifamily buildings are at a slightly higher risk of poverty, which may be due to lower energy efficiency standards in those types of dwellings (MCBE, 2017). Consequently, the difference in the multidimensional poverty rates of households living in detached houses and households living in multifamily buildings is much smaller than the differences shown by single indicators. Again, this is because the MEPI accounts for combinations of objective and subjective forms of deprivation.

Figure 5. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by type of building

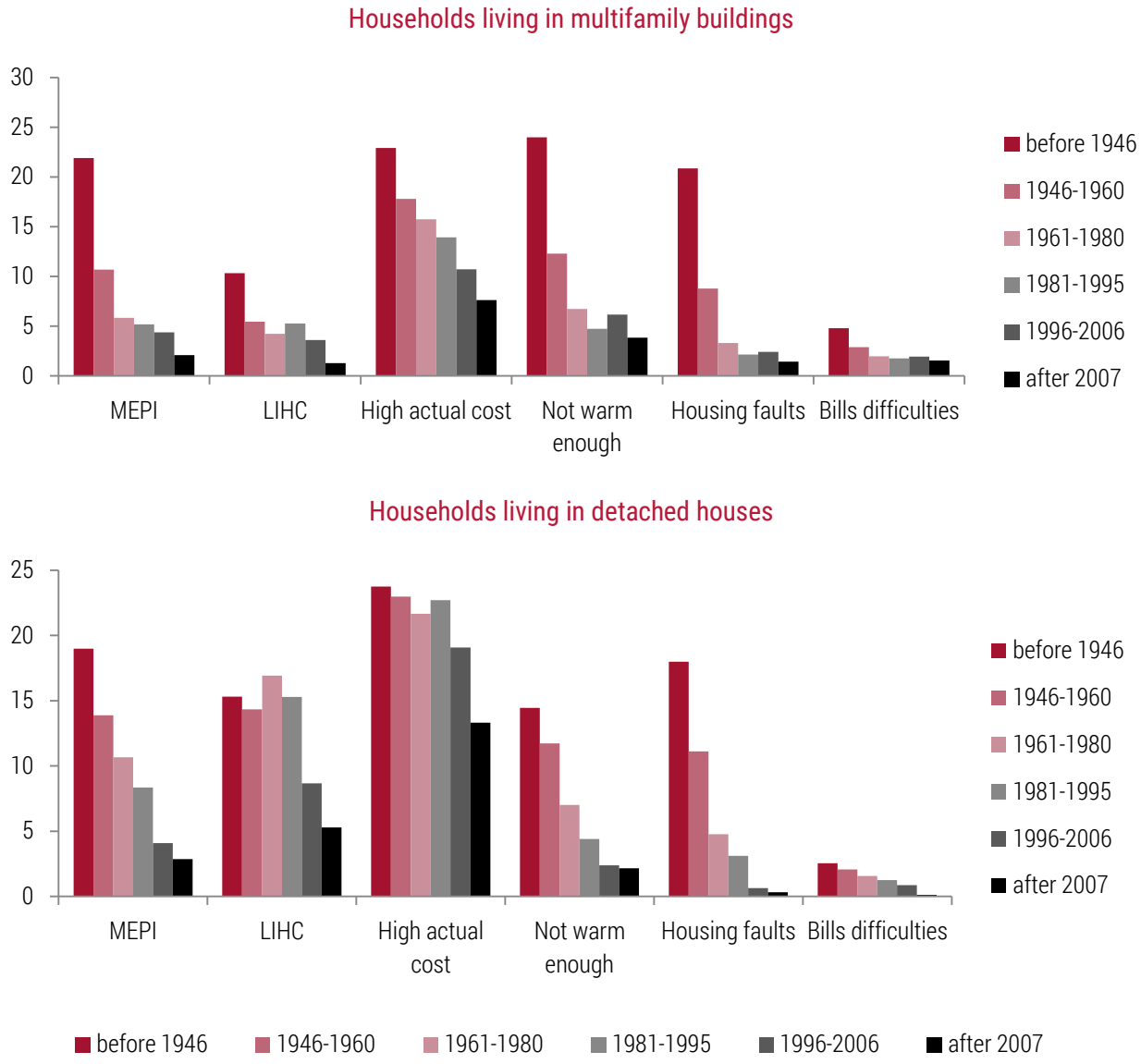


Source: Own calculations based on the Household Budget Survey data, 2017.

The older the building the household lives in is, the higher the household's risk of multidimensional energy poverty is. This is found to be the case for both detached and multifamily buildings, but the relationship between the age of the building and the risk of multidimensional poverty is stronger among households living in multifamily buildings (Figure 5). This finding can be traced back to two distinct features. First, according to subjective indicators, the risk of energy poverty is by far the highest among households living in multifamily buildings built before 1946. Applying the multidimensional index, we find that 74% of energy-poor households that live in multifamily buildings suffer from some form of subjective energy poverty. Second, according to the expenditure-based indicators, the risk of energy poverty is almost equally high among households living in all types of detached houses built before 1996. However, according to the subjective indicators, the risk of poverty increases with the age of the building (as in the case of multifamily buildings). By applying the multidimensional index, we find that the older a detached house is, the higher is the share of households affected by multiple forms of deprivation. According to the MEPI, 63% of energy-poor households that live in detached houses suffer from some form of subjective energy poverty. The MEPI shows that households living in older buildings face an

elevated risk of poverty, often because objective and subjective forms of deprivation overlap. Understanding these complex patterns is important for targeting of policies.

Figure 6. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by year of construction and type of building



Source: Own calculations based on the Household Budget Survey data, 2017.

Households that live in detached houses and households that live in multifamily buildings make up equal shares of all energy-poor households, according to the MEPI (Table 5). This means that household living in detached houses are slightly overrepresented among the energy-poor. Moreover, the structure of households identified as energy-poor suggests that there is a strong relationship between multidimensional energy poverty and the energy efficiency of the building. For example, 41% of all energy-poor households live in buildings constructed before 1946 (24% in multifamily buildings, 15% in detached buildings), while only 19% of the total population live in such buildings (11% and 8%, respectively). Furthermore, 29% of energy-poor households live in buildings built between 1961 and 1980 (13% in multifamily buildings, 16% in detached buildings), while the share of the total population living in such buildings is higher, at 35% (21% and 14%, respectively). Meanwhile, households living in newer buildings are underrepresented among the energy-poor.

Table 2. Structure of energy poor households, by type of building and year of construction (thousands of households)

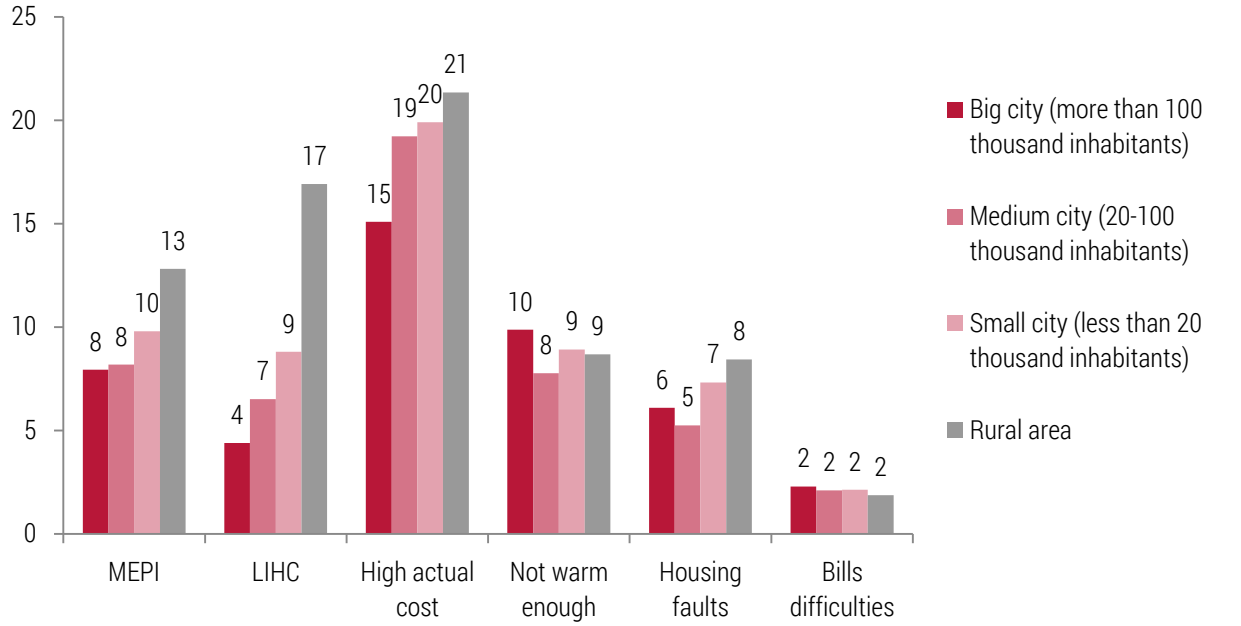
Type of building	Year of building construction	Energy-poor households		All households	
		Number of households	% among energy-poor	Number of households	% among all
Multifamily	Before 1946	317	24%	1 449	11%
	1946-1960	77	6%	720	5%
	1961-1980	169	13%	2 897	21%
	1981-1995	73	5%	1 407	10%
	1996-2006	19	1%	437	3%
	After 2007	10	1%	493	4%
	All	665	50%	7 404	55%
Detached	Before 1946	194	15%	1 025	8%
	1946-1960	124	9%	892	7%
	1961-1980	207	16%	1 938	14%
	1981-1995	104	8%	1 240	9%
	1996-2006	25	2%	620	5%
	After 2007	13	1%	452	3%
	All	667	50%	6 167	45%
Total		1 332	100%	13 571	100%

Source: Own calculations based on the Household Budget Survey data, 2017.

3.4. Spatial distribution of multidimensional energy poverty in Poland

The multidimensional energy poverty rate is highest among households living in rural areas (Figure 7). The same pattern can be observed for the LIHC "high actual costs" and "housing faults" indicators. For the "not warm enough" and "bills difficulties" indicators, no clear pattern related to the degree of urbanization can be seen. The differences in energy poverty between urban and rural areas can be traced back to the patterns pertaining to detached/multifamily buildings and sources of income described in the previous subsections: i.e., in rural areas and small towns, household incomes are, on average, lower than they are in cities, while the share of households depending on farming or welfare transfers (retirees, pensioners, recipients of other non-earned incomes) is higher, and the share of households living in detached houses is higher. As a result, households living in rural areas are overrepresented among the energy-poor, according to the MEPI (44% of the energy-poor households, compared to 33% of all households, are in rural areas, Table 6). Households living in large cities are underrepresented among the poor, but they still constitute 27% of all poor households due to their high share in the total population (34%).

Figure 7. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by size of place of residence.



Source: Own calculations based on the Household Budget Survey data, 2017.

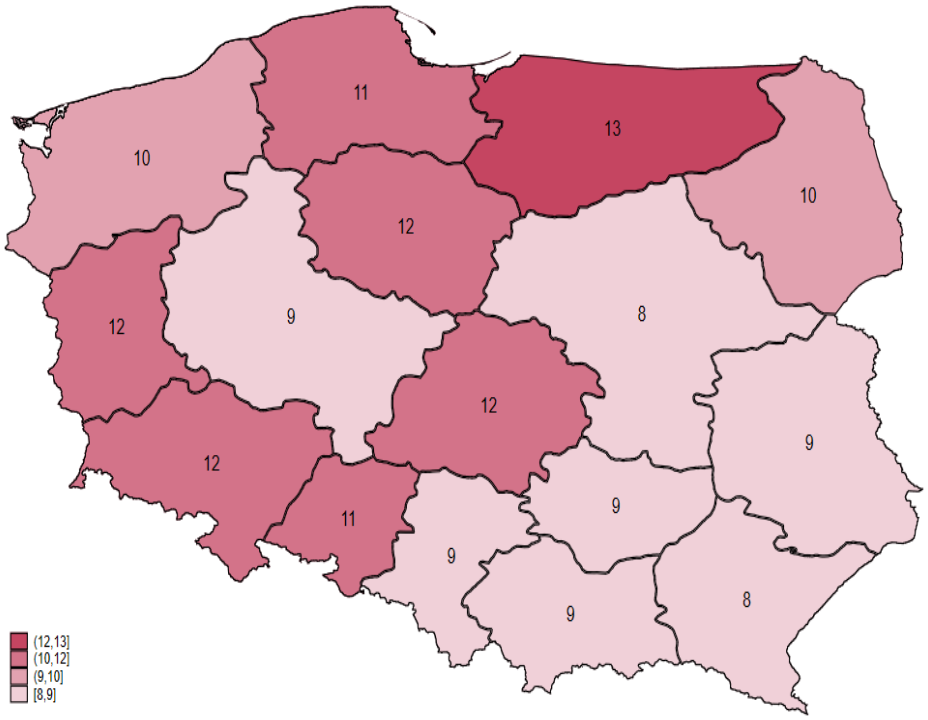
Table 6. Structure of energy poor households by size of place of residence (thousands of households)

Size of place of residence	Energy-poor households		All households	
	Number of households	% among energy poor	Number of households	% among all
Big city	364	27%	4 593	34%
Medium city	226	17%	2 762	20%
Small city	176	13%	1 793	13%
Rural areas	566	43%	4 423	33%
Total	1 332	100%	13 571	100%

Source: Own calculations based on the Household Budget Survey data, 2017.

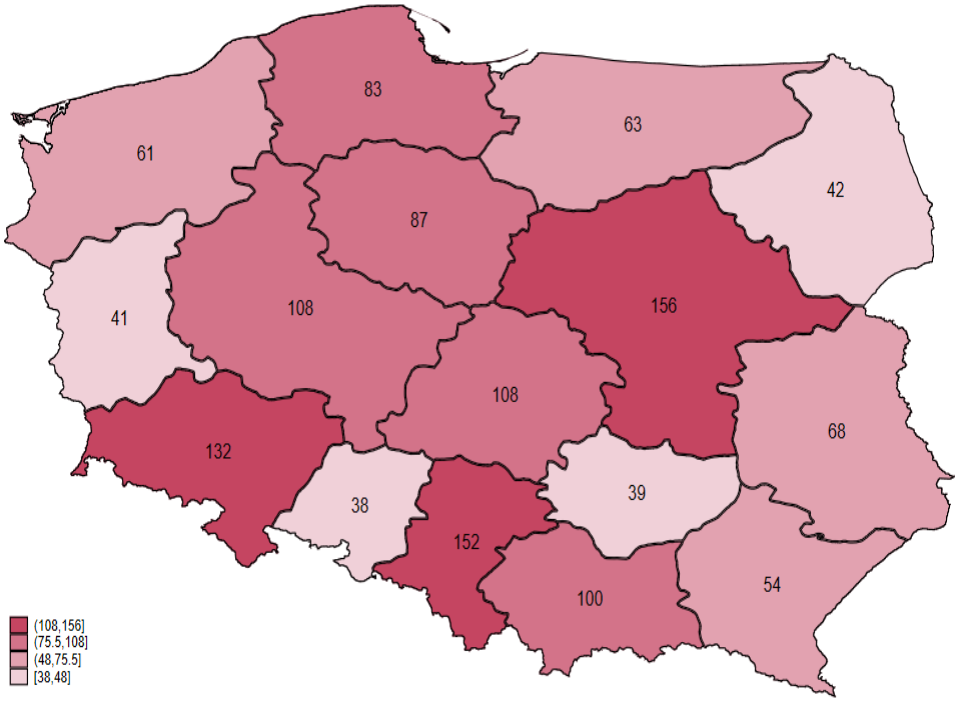
The rate of multidimensional energy poverty is highest in the northern and western regions of Poland, and is lowest in the eastern part of the country (Map 1). This pattern may seem counterintuitive, as the eastern regions are less urbanized and have lower average incomes than the central or western regions. However, the homes in the eastern regions are, on average, newer, and the incidence of subjective energy poverty, and in particular of "not being warm enough", is lower in the eastern regions than in the central or western regions (Lis et al., 2017). However, the regions with the highest poverty rates are not necessarily those where most of the energy-poor live. Indeed, the largest numbers of energy-poor households live in populous regions. The five largest regions (mazowieckie, wielkopolskie, śląskie, małopolskie, dolnośląskie) are home to 49% of all energy-poor households (52% of all households).

Map 1. Multidimensional energy poverty rate by NUTS2 regions in Poland (percent of households)



Source: Own calculations based on the Household Budget Survey data, 2017.

Map 2. The distribution of the multidimensional energy poverty rate by NUTS2 regions in Poland (thousands of households)



Source: Own calculations based on the Household Budget Survey data, 2017.

4. Conclusions

In this paper, we have developed a multidimensional energy poverty index that combines objective and subjective indicators of energy poverty. We used five indicators of energy deprivation, and defined energy-poor households as those that suffer from at least two forms of deprivation. We applied our index to Poland using five indicators that have been shown to be the most appropriate for measuring energy poverty in Poland (Sokołowski et al., 2019), and taking advantage of a rich, household-level dataset provided by the Polish HBS. We accounted for the following dimensions: low income combined with high required costs, high actual energy expenditures, housing defects, inadequate thermal comfort, and difficulties paying utility bills on time. By applying the multidimensional methodology, we were able to give equal importance to objective and subjective indicators, while at the same time developing an index that can be used for poverty mapping and policy planning.

We found that almost 10% (1.33 million) of households in Poland suffer from more than one dimension of energy poverty, and are thus poor in the multidimensional sense. Although the vast majority of these households have incomes that are low relative to the incomes of the general population in Poland, only half of these households are income-poor. We have identified three groups of households that face the greatest risk of multidimensional energy poverty. In terms of building characteristics, inhabitants of multifamily and detached houses built before 1946 face the highest risk (22% and 19%, respectively). In terms of the main source of income, retiree and pensioner households make up the largest share (44%) of the energy-poor. Finally, we found that energy-poor households are especially likely to live in rural areas (13%).

The Multidimensional Energy Poverty Index can be a useful for policy-makers wishing to develop a more detailed understanding of the characteristics of energy-poor households, which is essential for targeting support. We assume that the coincidence of multiple dimensions of energy poverty puts a household in a far worse situation than if they were dealing with only a one form of deprivation. Additionally, directing support to households based on the findings of the MEPI could be more straightforward than using multiple indicators and prioritizing them.

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Appendix

A1. Methods of calculating single indicators of energy poverty – detailed description

1. Low income, high cost (LIHC)

"Low income, high cost" identifies as energy-poor households that meet two criteria simultaneously: namely, they have high required energy expenditure and a low income.

A. High required energy expenditure

The high required energy expenditure criterion is met if the required equivalent household energy expenses are higher than the median of the equivalent energy expenditure in the population.

- Household energy expenditure is the sum of spending on electricity and heat.
- Required household energy expenditure is the level of energy expenditure – given the characteristics of the household and the building, and the energy prices (depending on the type of heating) – which allows the household to maintain the optimal temperature in the dwelling, and to make adequate use of lighting and appliances.

  The optimal solution would be to implement a model that calculates the required level of energy expenditure for a given household while matching the building characteristics and the type of heating.

  Due to the lack of such data, required energy expenditure is calculated based on the actual energy expenditure of the household in a given year. The value of the required energy expenditure is determined for 84 categories, according to the type of building (multi-family, detached or semi-detached house, single-family detached house), type of heating (central heating, fuel stoves, electric stoves, gas stoves) and period of building construction (seven levels).

  The required energy expenditure is the sum of the required expenditure on electricity and heat. The required expenditure on electricity for a given household is the average of the expenditure on electricity per person multiplied by the number of people in the household in a particular household category. The required expenditure on heat for a given household is the average of the expenditure on heat per square meter, multiplied by the usable floor area of a building in a particular household category.
- In the context of heat expenditure, we introduce the concept of under-occupation. The under-occupation of a dwelling is defined by the presence of two conditions: the Parker Morris criterion (based on: DECC, 2016) and the Eurostat criterion (based on: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Under-occupied_dwelling).

  According to the Parker Morris criterion, the dwelling is under-occupied if the dwelling exceeds a certain size depending on the number of people in the household: 66 m^2 for one person, 97 m^2 for two people, 122 m^2 for three people, 158 m^2 for four people, 179 m^2 for five people, 194 m^2 for six people, 229 m^2 for seven people, and 256 m^2 for nine or more people.

  According to the Eurostat criterion, the dwelling is under-occupied if it has more than an adequate number of rooms given the household composition. The adequate number of rooms is the sum of: one common room, one room for a couple in a relationship, one room for two children of the same sex between the ages of 12-17, one room for two children under age 12 regardless of gender, and one room for every other person.

We assume that the part of dwelling that is under-occupied according to the Parker Morris criterion is not being used, and that the required energy expenses of the household are reduced accordingly.

- For the equivalised required energy expenditure, we use a scale with a two-person household as a reference point. The coefficients for the households with a given number of people are obtained by dividing the median required energy expenditure of households with a given number of people by the median required energy expenditure of a two-person household.

B. Low income

The low income criterion is fulfilled for households that meet two conditions simultaneously. The first condition is met if the equivalent income of the household is in the lowest 30% of incomes in the population. The second condition is met if the equivalent household income after housing costs is lower than the individual income threshold.

- The equivalent disposable income of households is set according to the modified OECD equivalence scale: the first adult is assigned a weight of one, each next person aged 14 or older is assigned a weight of 0.5, and each child under age 14 is assigned a weight of 0.3.
- In order to calculate the household income after housing costs, the expenditures on water supply and other services, rent, and mortgage payment are deducted from the disposable income of the household.
- The equivalisation of income after housing costs is performed according to the Fuel Poverty scale: the first adult is assigned a weight of 0.58, each next person aged 14 or older is assigned a weight of 0.42, and each child under age 14 is assigned a weight of 0.2.
- The threshold of equivalent income after housing costs is determined individually; i.e., separately for each household. The threshold is the sum of two components: 60% of median equivalent incomes after housing costs in a population and the required equivalent energy expenditures of a given household.

2. High share of energy expenditure in income (high actual cost)

According to this indicator, the households with a high share of actual energy expenditure in income are identified as energy-poor. The threshold is twice the median of this value in the population.

- Household energy expenditure is the sum of spending on electricity and heat.
- While counting the threshold, we do not take into account the households in the first percentile of income. These are the households that have a very low income, or have an income at the zero or negative level. However, we identify these households as energy-poor based on the "high expenditure" index.

3. Inability to keep the home adequately warm (not warm enough)

The indicator is created based on the following survey question: "In your view, is your apartment warm enough in the winter (i.e., does your building have technically efficient heating and sufficient insulation)?" The households answering "no" are identified as energy-poor.

4. Presence of leak, damp or rot (housing faults)

The indicator is created based on the following survey question: “In your view, does your apartment have a leaking roof; damp walls, floors, or foundations; or rotting window frames or floors?” The households answering “yes” are identified as energy-poor.

5. Inability to pay utility bills (bills difficulties)

The indicator is created based the following survey question: “Considering the last 12 months, how would you rate your satisfaction with your household's needs regarding the payment of housing-related bills on time (fixed costs, rent, rental costs, etc.)?” The households answering “low” and “rather low” are identified as energy-poor.

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