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A multidimensional index to measure energy poverty: the Polish case

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ABSTRACT

Energy poverty is generally caused by having a low income, facing high energy costs, and living in a home with low energy efficiency. Various indicators capture these facets, but there is no consensus which is the best one, or how to combine them. To this aim, we create a multidimensional index that accounts for five dimensions of energy deprivation: two objective indicators of "low income, high costs," and "high actual cost," as well as three subjective indicators of "not warm enough home," "housing faults," and "bills difficulties." We define households as poor if at least two forms of deprivation are present. We apply our measure to Poland. In 2017, 10% of households in Poland suffered from multidimensional energy poverty. Households living in buildings built before 1946, households living in rural areas, and households that were dependent on retirement and disability pensions were at the highest risk of multidimensional energy poverty.

1. Introduction and motivation

The issue of energy poverty has gained recognition among researchers and policy-makers since the seminal work of Boardman (1991). However, defining energy poverty poses a scientific challenge, due to differences in experiencing and understanding energy poverty. First of all, there is a dichotomy between defining energy poverty in developing and developed countries. In developing countries, energy poverty is usually understood as the lack of access to energy services (Sokołowski 2019; Sovacool 2012), while in developed countries it is understood in terms of energy expenditures and incomes (Buzar 2007). Secondly, even within this dichotomy, the quality and costs of energy services, as well as building characteristics differ across countries, so it is unlikely that a single indicator can be applied in various contexts. Moreover, definitions of energy poverty become increasingly more complex. For instance, Bouzarovski and Petrova (2015) distinguished between fuel and energy poverty, and Day, Walker, and Simcock (2016) applied the capabilities framework to emphasize the role of access to energy services (or lack thereof) in achieving socio-economic wellbeing and sustaining quality of life. We take stock of the capabilities approach, and we relate energy poverty to household situation. We define energy poverty as a situation when a household is unable to afford the energy needed to provide its members with adequate warmth, cooling, lighting, and appliance use (Thomson, Bouzarovski, and Snell 2017).

We contribute to the literature on energy poverty measurement by proposing a multidimensional index that accounts for the multi-faceted nature of energy poverty, but also results in a single indicator that can be used for poverty mapping and policy planning. We combine objective and

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subjective indicators (five in total). We apply similar definitions and metrics as those used to study energy poverty in Europe (Buzar 2007; Thomson and Snell 2013; Tirado Herrero and Ürge Vorsatz 2012). We also acknowledge the research on multidimensional energy poverty in developing countries (Bhatia and Angelou 2015; Nussbaumer et al. 2011). By proposing a multidimensional index, we address the key drawback of using single indicators only: namely, conflicting interpretations and results of different indicators. 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. The index allows understanding of the coincidence of different facets of poverty at the household level, estimating the incidence of energy poverty in a given population, as well as between-group comparisons.

We base our methodology on Alkire and Foster (2011) who comprehensively examine multidimensional poverty measurement and methodology. By combining monetary and non-monetary indicators of energy poverty we follow Alkire et al. (2015) key argument (in line with Nolan and Whelan 2011) that multidimensional poverty measures which account for both monetary and non-monetary indicators are better than single monetary indicators. First, non-monetary indicators complement the monetary ones with a concept of what it really means to be poor. Second, they capture the lack of resources and can reflect the households' capabilities. Third, as poverty is multidimensional phenomenon, it should be measured with multiple indicators.

We present an example of application to Poland, taking advantage of rich Household Budget Survey data. Energy poverty poses a serious challenge for public policy in Poland (Bouzarovski and Tirado Herrero 2017; Rutkowski et al. 2018). Importantly, our indicator can be applied to other EU countries (and comparisons between them) as the set of indicators used in our measure is consistent with those recommended by the EU Energy Poverty Observatory. Of course, researchers may want to modify the set of deprivations and indicators pertaining to them in order to capture the country-specific characteristics of energy poverty in the best possible way. While our work is open for refinement, we hope it is a step forward in improving social welfare indicators.

The article is organized as follows. In the second section, we review the relevant literature on defining and measuring energy poverty, and constructing multidimensional indicators. In the third section, we outline our methodology and data. In the fourth section, we present and discuss the results. The fifth section concludes. The appendix presents additional methodological details on how particular indicators were constructed.

2. Literature review

2.1. *Single energy poverty indicators*

The academic debate on suitable energy poverty metrics follows the discussion of the appropriate energy poverty definition, and several approaches are applied. The most common typology of metrics distinguishes qualitative (subjective) and quantitative (objective) indicators (Price, Brazier, and Wang 2012). Qualitative indicators rely on self-assessed situation of households regarding e.g.: housing situation, ability to pay utility bills or achieve thermal comfort (Healy and Clinch 2002; Kose 2019; Thomson, Bouzarovski, and Snell 2017). Quantitative metrics are based on the incomes and expenditures reported in surveys and/or modeled, as recent studies tend to rely more on the required energy cost rather than the actual cost.[1] The most commonly applied quantitative measures are: Low Income, High Cost (Heindl 2015; Hills 2012; Imbert, Nogues, and Sevenet 2016; Lewandowski and Sałach 2018), absolute threshold of energy spending in relation to income (e.g., '10% energy poverty threshold' as in Boardman 1991; Legendre and Ricci 2015) and metrics based on median expenditures (Tirado Herrero and Ürge Vorsatz 2012).

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[1]By required energy cost we understand the cost that the household needs to incur in order to satisfy its energy needs, given the housing situation and household composition.

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 facets 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. Finally, the measurement should strike a balance between accuracy and complexity, and efficiency in informing policymakers (Pelz, Pachauri, and Groh 2018). 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).

Using a group of objective and subjective indicators independently has advantages: it accounts for a diversity of concepts of energy poverty, and presents a broader picture than any single indicator could. It allows measuring energy poverty in terms similar to capabilities approach (Day, Walker, and Simcock 2016), as the importance of energy services for the quality of life can be better understood thanks to capturing the relationship between energy poverty, and housing condition or thermal comfort.

However, using a group of indicators independently also has disadvantages, especially if they are used for social policy, and if different indicators show different results (Romero, Linares, and López 2018). This is the case in Poland, a country for which we implement our multidimensional index. Based on the EPOV (2018) metrics, data quality and availability, as well as quantitative and qualitative assessment, Sokołowski, Kiełczewska, and Lewandowski (2019) recommended five indicators that capture key dimensions of energy poverty in Poland: 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. However, in 2017 the share of households affected by particular deprivations ranged from 2.2% (problems with paying utility bills) to 18% (high actual expenditure, Sokołowski, Kiełczewska, and Lewandowski 2019). Furthermore, the objective indicators show that inhabitants of detached homes are at the highest risk of energy poverty in Poland, while the subjective indicators indicate that inhabitants of old multifamily buildings are at the highest risk of being affected. Such discrepancies pose challenges for policy-makers and can create confusion regarding the rate of energy poverty and the characteristics of energy-poor households.

2.2. Multidimensional energy poverty indices

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. Recently, the Alkire-Foster methodology (Alkire et al. 2015) has become the leading approach to construct multidimensional indicators. However, to the best of our knowledge, so far it has not been applied to energy poverty in Europe. Nussbaumer et al. (2011), and Sadath and Acharya (2017) used it to measure energy poverty in developing countries, but, due to data limitations, accounted only for self-reported forms of deprivation. Finally, Okushima (2017) applied the Alkire–Foster method in a developed country (Japan), but based on income/expenditure data, without accounting for self-reported characteristics of energy poverty. To the best of our knowledge, our article is the first to combine objective and subjective indicators of energy deprivation.

There are two groups of methods of multidimensional poverty measurement (Alkire et al. 2015). In the first group, aggregate data are used. In the second group, the information on particular poverty dimension for single unit of analysis (a household) is used. We use the latter method which allows identifying households considered multidimensionally poor via the joint distribution of deprivations at the household level (coincidence of different facets of poverty). Thus, we contribute to the literature on composite measures of energy poverty as the previous attempts were based on aggregate data. Thomson and Snell (2013), and Gouveia, Palma, and Simoes (2019) calculated composite indices of energy poverty, while Bollino and Botti (2018) computed a compound indicator based on fuzzy sets methodology. Bouzarovski and Tirado Herrero (2015) developed an index as

a weighted mean of the share of households facing problems with utility bills (weighted 0.5), inadequate living conditions (0.25), and insufficient thermal comfort (0.25). Although useful for making comparisons across countries, the composite indices cannot be applied to measure the incidence of poverty at the household level.

By studying the joint distribution of deprivations at the household level, we are also able to capture the differences in the distribution of deprivation forms across households. Assume one scenario in which three households are affected by one deprivation measure each, and another scenario in which one household is affected by three deprivations while the other two households are not affected at all. A multidimensional approach that we use will show different results for each scenario, as it identifies the households with coinciding dimensions of energy poverty. The compound index, however, will show the same value in both scenarios, even though the underlying experiences of energy poverty are very different.

3. Methodology and data

3.1. *Selection of indicators*

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 the 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. Their definitions are presented in Table 1 and methodology of each indicator is described in detail in the appendix.

There are three main arguments for using this group of indicators. First, these indicators belong to those recommended by EPOV (2018) and as independent indicators they were shown to be the most suitable measures of energy poverty in Poland. Their selection was confirmed in the extensive consultations with Polish and European policymakers and stakeholders (Sokołowski, Kiełczewska, and Lewandowski 2019). In particular, they were accepted by the Polish Ministry of Energy as indicators on which the policy responses to energy poverty may be based.[3]

Second, these indicators convey complementary information. The correlations and redundancy measures (Alkire et al. 2015) between particular dimensions of energy poverty across Polish house-

Table 1. Single dimensions of energy poverty.

Indicator	Abbreviation	Household is deprived if:
Low income, high costs	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. Household has low income if its income is below the 30th percentile of equivalent income,[2] and is below 60% of the median equivalent income less housing costs n population.
High share of energy expenditure in income	High actual costs	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.

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[2]The 30th percentile threshold was also used by Belaid (2018) for France, and Okushima (2017) for Japan.
[3]In 2019, Ministry of Energy, responsible for tackling energy poverty in Poland have been dissolved.

Table 2. Cross-correlations and redundancy measures (%) of single dimensions of energy poverty in Poland.

	Low income, high costs	High actual costs	Not warm enough	Housing faults	Bills difficulties
	Cross-correlations				
Low income, high costs	1.00				
High actual costs	0.18	1.00			
Not warm enough	0.03	0.05	1.00		
Housing faults	0.03	0.05	0.30	1.00	
Bills difficulties	0.05	0.06	0.09	0.13	1.00
	Redundancy analysis (%)				
Low income, high costs	n/a	40.2	12.0	13.2	19.9
High actual costs		n/a	24.9	25.6	34.0
Not warm enough			n/a	40.4	27.4
Housing faults				n/a	28.5
Bills difficulties					n/a

Note: the redundancy measure between a pair of indicators is defined as the number of households which experience deprivation according to both indicators, as a proportion of the minimal number of households which experience deprivation to either indicator (Alkire et al. 2015).
Source: Own calculations based on the Household Budget Survey data, 2017.

holds in 2017 are quite low (Table 2). The highest correlation is between two subjective deprivations (0.30), followed by the correlation between two monetary measures (0.18). The correlations between any pair of monetary and subjective deprivations are very low and do not exceed 0.13. The highest observed redundancy measures are only 40% (between two subjective indicators, and between two monetary indicators). This proves that the chosen dimensions of deprivation convey complementary information and capture different aspects of energy poverty.

Third, including more indicators is not desirable. In particular, we decide against using a fixed-threshold of spending indicators, which are arbitrary and may lead to path-dependency in defining energy poverty (Bouzarovski and Petrova 2015). They also provide implausible results for Poland[4]

3.2. *Methodology of multidimensional index*

We calculate the multidimensional energy poverty index using the methodology outlined by Alkire et al. (2015) and Alkire and Apablaza (2017). The joint distribution of deprivations that any unit of the analysis (a household) may experience is defined by the set of deprivations, D. We use the dual-cutoff approach. First, for every household i, we set a deprivation matrix assigning a value of one if the household is deprived in a given dimension $d \in D$, and a value of zero if it is not. Second, for each household, we add the positive entries, weighting each dimension with an equal weight, i.e., $w_d = 1/5$ for every $d \in D$, to obtain the weighted sum c_i is the deprivation score (the weighted share of deprivations at a household level). We think that each dimension of deprivation is an essential aspect of energy poverty so we treat each dimension as equally important.[5] Equal weights are commonly used in studies of multidimensional poverty in which none of dimensions is considered as the most important (e.g., Alkire and Apablaza 2017).

A household is identified as poor if its weighted deprivation score c_i is higher than the poverty cutoff, $k = 0.4$. Thus, a household with at least two out of five types of deprivation is treated as energy poor, while a household with only one deprivation is not considered poor. We think that two deprivations are enough to recognize a household as energy poor. Deprivation in only one dimension may not necessarily indicate energy poverty as it may result from other circumstances or measurement error. However, deprivation in another dimension validates that energy poverty is an issue for a given household. On the other hand, the

[4]Adopting the absolute 10% energy expenditure threshold (applied in the UK until 2012) would result in implausibly high incidence of energy poverty: almost a half of the Polish population would be considered energy poor (Lis, Miazga, and Sałach 2017).
[5]The role of weights in the dichotomous counting approach that we apply is different than in the composite indices. In the composite indices weights are crucial in determining the trade-offs between the deprivation dimensions. In the dichotomous counting approach, weights just directly reflect the relative impact the individual dimensional deprivations has on the individual deprivation score (Alkire et al. 2015).

incidence of three or more dimensions is very rare in Poland (it concerns only 2% of households, see Section 4), thus using a cutoff of $k = 0.6$ would imply selecting a small number of severely deprived households.

Finally, we calculate the headcount ratio *(H)* as the share of households that are multi-dimensionally poor, the average deprivation among the energy poor households *(A)*, and the adjusted headcount ratio M_0 that accounts for the number of deprivations that poor people experience. We focus, however, on H, since we want to compare the multidimensionally poor population with populations that are deprived according to particular indicators (for which only the *H* can be calculated). Moreover, in section 4 we show that 80% of the multidimensionally poor households suffer from exactly two deprivations, so we will present results for *A* and M_0 only for groups that noticeably differ in *A*.

3.3. *Data*

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. It also covers dwelling characteristics and subjective assessment of 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). We drop observations with missing data and obtain a sample 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).[6] We recalibrate the weights in the reduced sample to ensure representativeness with respect to age and sex, following Myck and Najsztub (2015). The original weights in the HBS data are representative only at the household level (due to number of household members and urban/rural areas). Myck and Najsztub (2015) showed that reweighting according to individual characteristics, such as age and sex, improves the accuracy of the calculations. This is important as we calculate statistics on the household level, as well as on the individual level.

4. Results

4.1. *Multidimensional energy poverty index – composition by forms of deprivation*

We find that 1.33 million out of 13.57 million households (9.8%) in Poland are multidimensionally energy-poor (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 of households identified as multidimensionally poor are affected by exactly two forms of deprivation (1.06 million, 7.8% of population and 80% of the poor, Table 3). The number of households affected by at least three forms of deprivation is much lower (314 thousand, or 2% of households). On the other hand, 25% of households in Poland are deprived in exactly one dimension, while two in three households are not affected by any dimension of energy poverty.

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 (Figure 1). 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. Moreover, the multidimensional index exhibits higher precision than single indicators, as its standard error is lower than the standard errors of single indicators (except for the high actual cost indicator).

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[6]Some subpopulations are not at all covered by the survey design, e.g., homeless people.

Table 3. 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

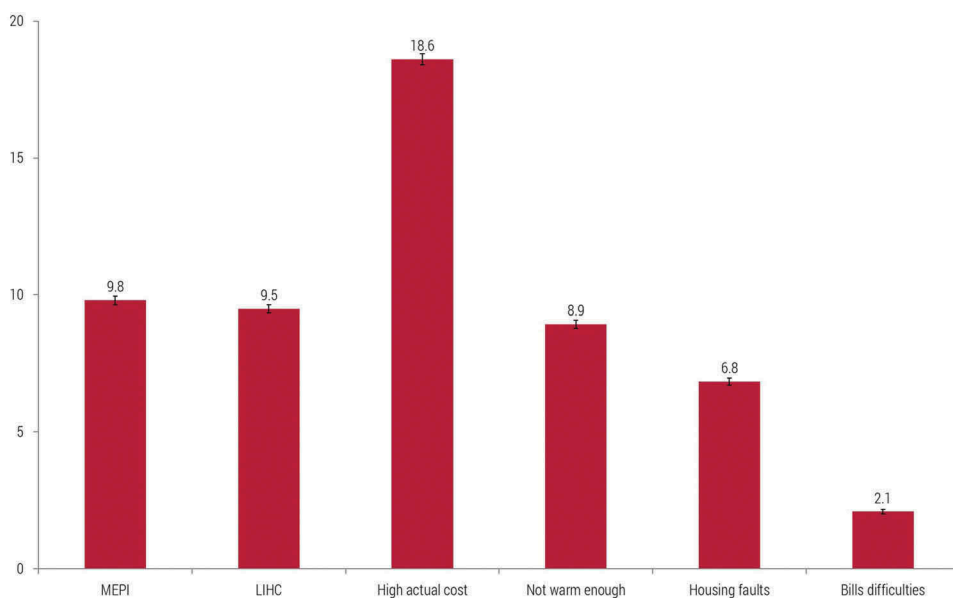*Source: Own calculations based on the Household Budget Survey data, 2017.*

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

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

Among the multidimensionally energy-poor households, the combination of two expenditure-based forms of deprivation ("low income, high costs" and "high expenditure") is the most common (31% of poor household), followed by the combination of two subjective forms of deprivation ("leaks, damp, or rot" and "not warm enough," 16%, see Table 4). Although the experience of energy poverty in these subgroups may be different, 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). Forty-eight percent of households identified as multidimensionally energy-poor 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 multi-dimensional approach.

A simple compound index with equal weights applied to our indicators would show a 9.2% energy poverty rate, while the Bouzarovski and Tirado Herrero (2015) methodology would show 5% rate. Although the rates shown by the compound index (9.2%) and the multidimensional index (9.8%) are comparable, a compound index assumes substitution between energy poverty dimensions. This is especially problematic in Poland where a high risk of energy poverty in terms of expenditures

Table 4. Energy-poor households, by dimensions of the poverty.

Dimensions of the energy poverty						
Low income, high costs	High actual costs	Not warm enough	Housing faults	Bills difficulties	Number of households (thousands)	Share among energy-poor (%)
*	*				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.

would be compensated in the compound index by a low risk of problems with utility bills. The multidimensional index is also more robust to changes in the set of indicators: assume that the indicator with the lowest incidence and the highest error (bills difficulties) is removed from the indicators set. The compound index based on the remaining four indicators would increase to 11.0%, while the multidimensional indicator would decrease to 9.2%. Both approaches allow estimating the energy poverty rate, but the multidimensional index is superior in quantifying the coincidence and relations between various deprivations.

4.2. 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 is the case especially for the multidimensionally poor (Figure 2). Groups deprived according to the LIHC and the "bills difficulties" indicators also exhibit rather low incomes – the median equivalised income in these groups is visibly lower than the 1st quartile of the overall equivalised income distribution (Figure 2). The incomes of households that are deprived according to the "high actual costs," "not warm enough," and "housing faults" indicators are higher. Some households that belong to these groups have incomes in the 4th quartile of the overall distribution. However, these households are not classified as poor according to the multi-dimensional indicator, which is its key advantage. While the multidimensional index identifies energy-poor households who are not income-poor, it does not identify as poor households with relatively high incomes who are affected by a single deprivation.

Slightly more than a half (53%) of multidimensionally poor households are also income-poor. The share of income-poor households is similar for the "bills difficulties" indicator, higher for the LIHC
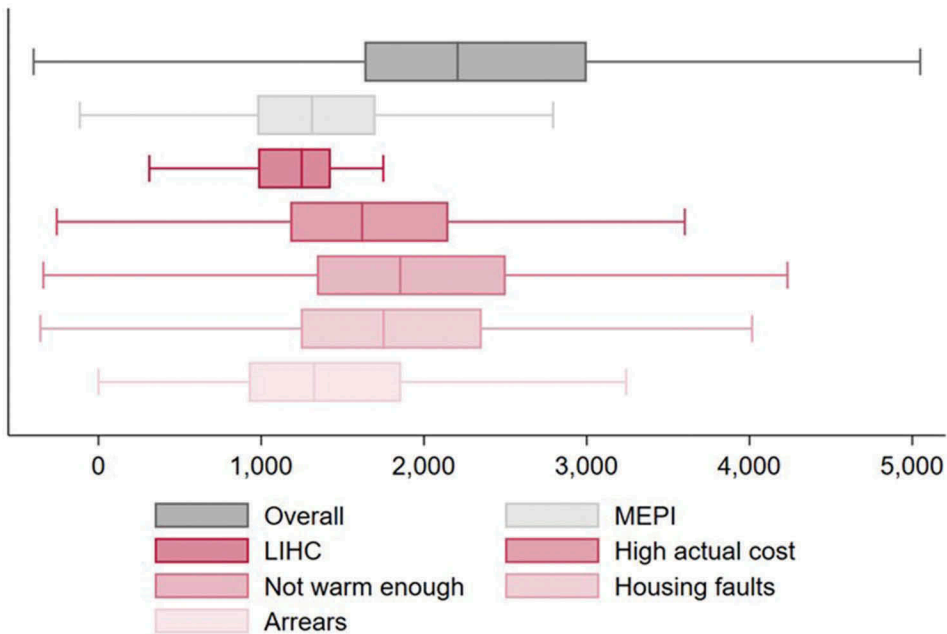
Figure 2. Equivalised income of households – overall and for energy-poor households (multi-dimensionally and according to single indicators).

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.

indicator, and lower for the other single dimensions of deprivations (Figure 3). These disparities between income and energy poverty are likely to be of special interest to policy-makers, as they may be related to 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. Finally, households affected by multidimensional poverty are potentially in the worst situation in terms of satisfying their energy needs.

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, these groups differ in the structure of deprivations. 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.[7] The risk of energy poverty among farmers can be overestimated according to objective indicators, especially "low income, high costs," since farmers may experience seasonal income fluctuations, and often live in large area houses

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[7]Farmers' expenditures and incomes are comparable and they are accounted for in the best possible manner in the process of data collection. The vast majority of households living of farming in Poland are subsistence farming. The legal system in Poland does not treat subsistence farms as businesses – the farms are exempt from income tax (and are not covered by the accounting rules). Statistics Poland applies its methodology of measuring farmers' incomes and expenditures in HBS. It is aimed at ensuring, among others, that the business expenditures are not counted as private consumption spending.
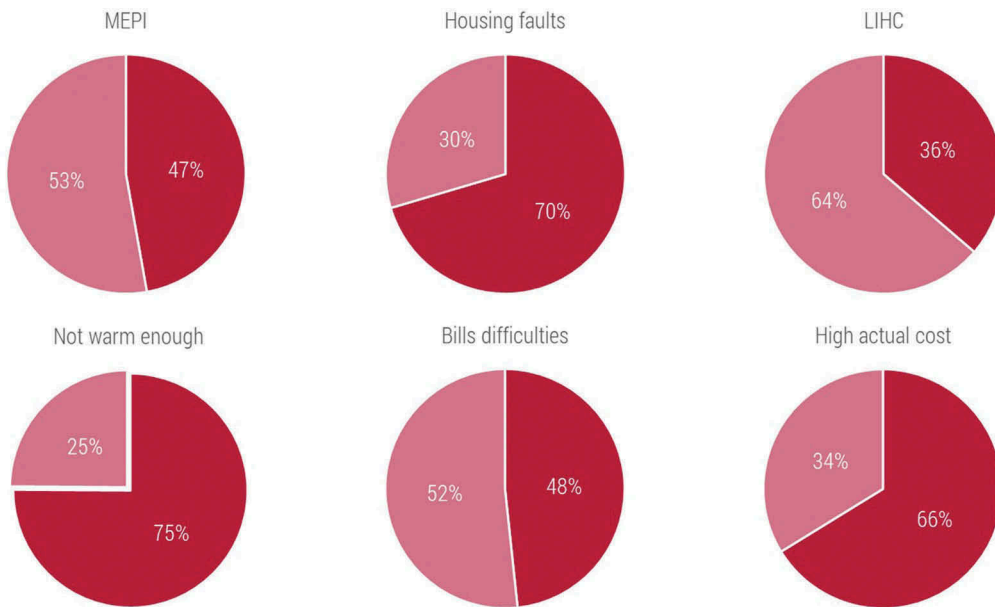
Figure 3. Income poverty among energy-poor households (multi-dimensionally and according to single indicators).
Source: Own calculations based on the Household Budget Survey data, 2017.

(Lewandowski, Kiełczewska, and Ziółkowska 2018). Accounting for multiple deprivations is therefore particularly desirable in the case of farmers' households.

Households of retirees and pensioners, recipients of non-earned income sources, and blue-collar workers are the three most numerous groups among the multidimensionally energy-poor, and jointly constitute 78% of all multidimensionally energy-poor households (Table 5). Retirees and pensioners and recipients of non-earned income sources represent a higher share among the energy-poor in comparison to their shares in the total population. Farmers are also over-represented. 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 the largest 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%).

4.3. Multidimensional energy poverty and building characteristics

The risk of energy poverty in Poland is strongly related to the characteristics of dwellings. The multidimensional 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, Kiełczewska, and Ziółkowska 2018), which translates into higher heating costs. On the other hand, the subjective indicators show that households living in multifamily buildings are deprived slightly more often, 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.
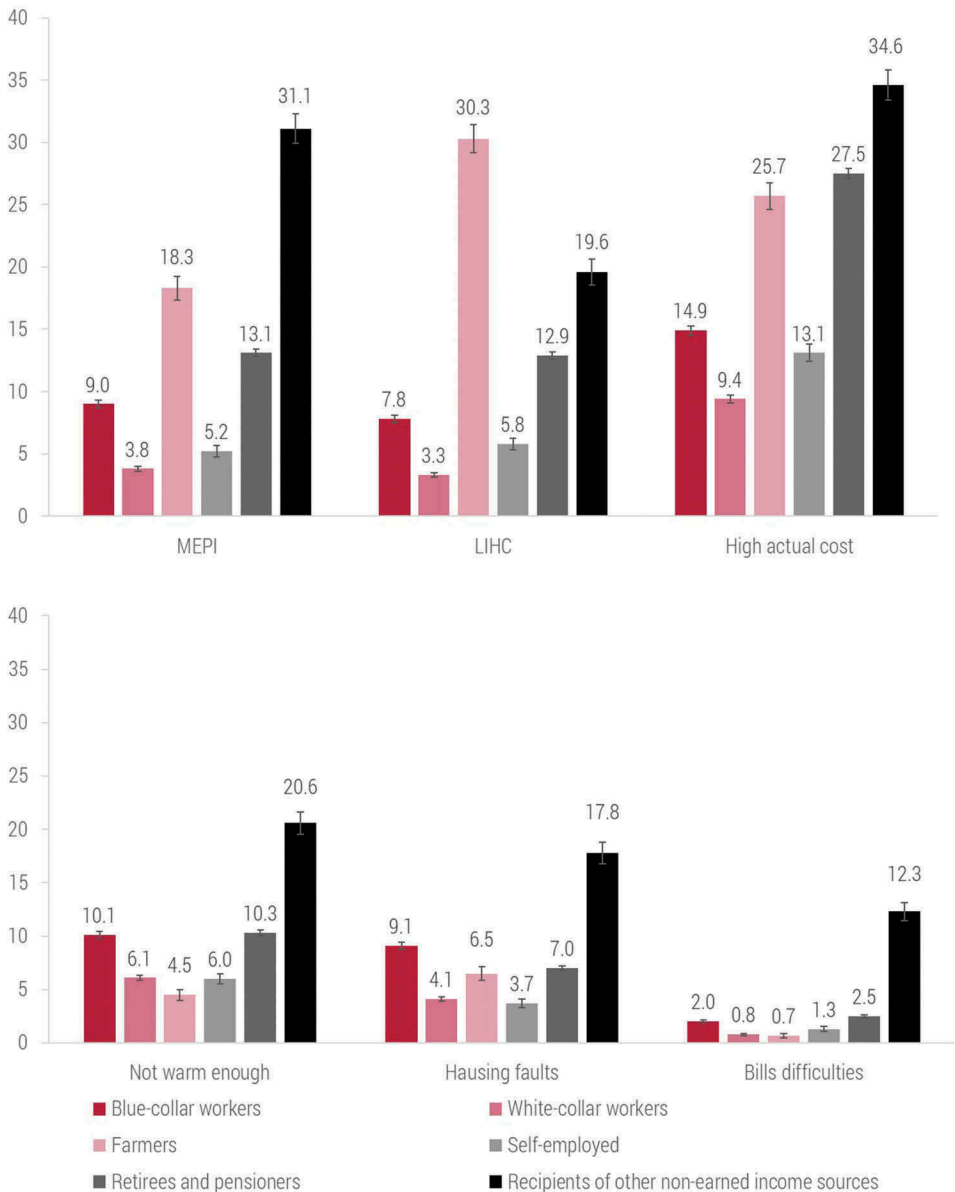
Figure 4. Multidimensional energy poverty index and single dimensions of energy poverty, by main source of household income (percent of households).

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

The older the building the household lives in is, the higher the household's risk of multidimensional energy poverty is. The relationship between the age of the building and the risk of multidimensional poverty is stronger among households living in the multifamily buildings than among households living in detached houses (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. Indeed, 74% of multidimensionally 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

Table 5. Energy-poor households, by dimensions of the form of poverty.

	Energy-poor households		Energy- and income-poor households		All households	
Main source of income	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.
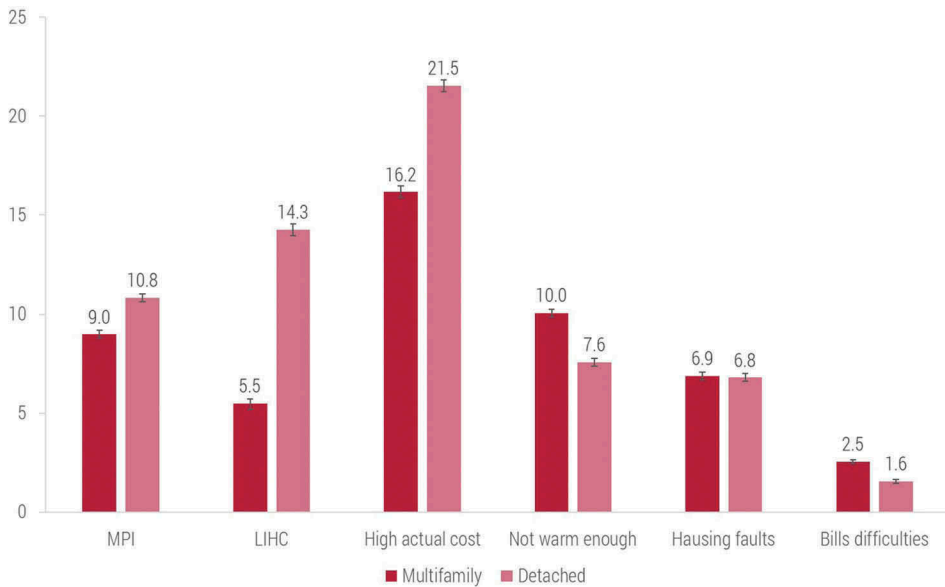

Figure 5. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by type of building.

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

deprivation 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 deprivation increases with the age of the building (as in the case of multifamily buildings). Thus, the older a detached house is, the higher is the share of households affected by multiple forms of deprivation (Figure 6). Sixty-three percent of multidimensionally 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 higher risk of poverty, often because objective and subjective forms of deprivation overlap. Understanding these complex patterns is important for targeting of policies.

Note that single indicators, and especially the "bills difficulties," exhibit higher standard errors than the MEPI, especially in the case of buildings built after 2007. Application of MEPI improves statistical reliability of within-group estimates of poverty rates.
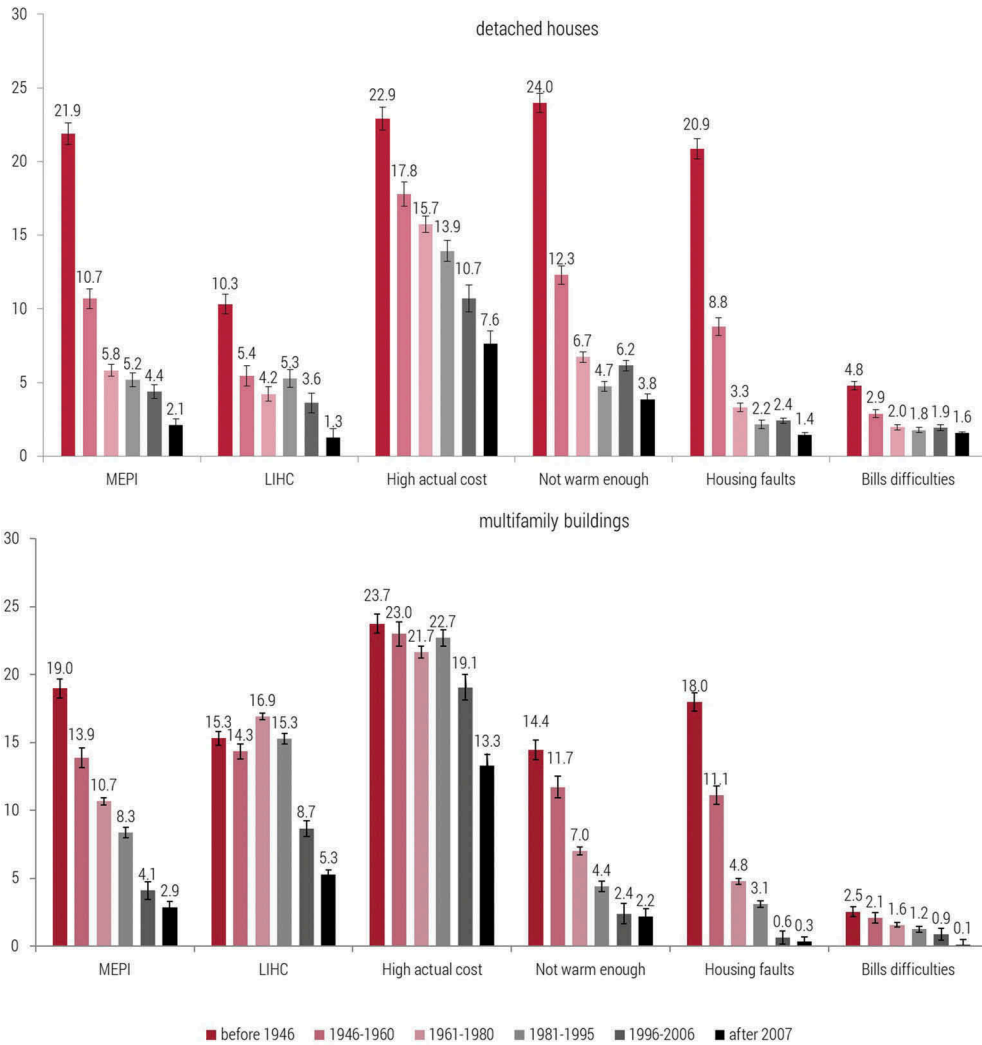
Figure 6. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by year of construction and type of building.

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 multidimensionally energy-poor households (Table 6). 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 represent a lower share among the energy-poor. To sum up, our results suggest a strong relation between the year of building construction and multidimensional energy poverty.

Table 6. 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.

4.4. Spatial distribution of multidimensional energy poverty in Poland

The multidimensional energy poverty rate is the 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, there is no clear pattern related to the degree of urbanization. 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.
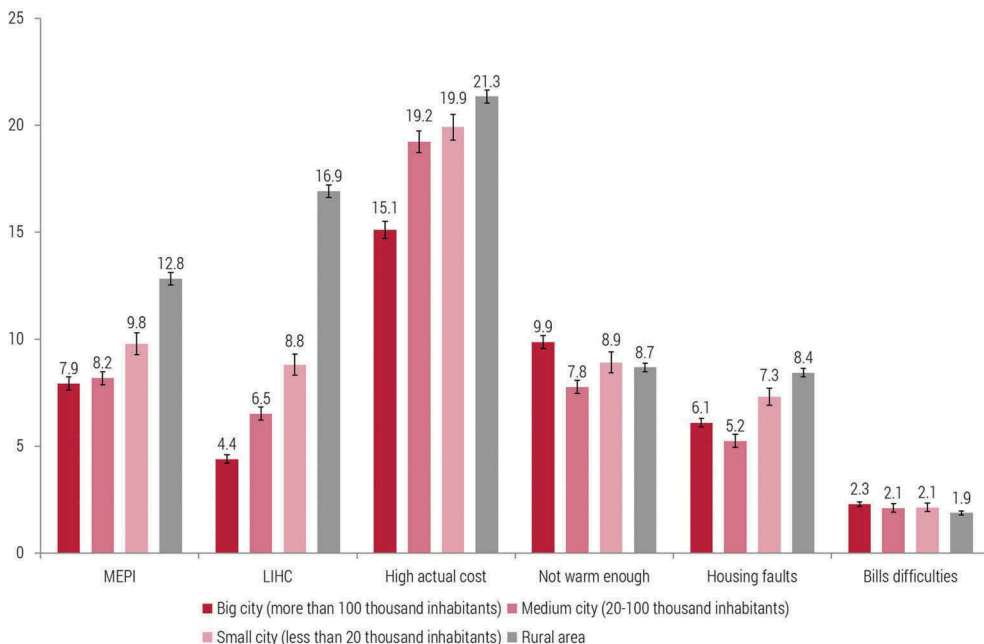

Figure 7. Multidimensional energy poverty index and single dimensions of energy poverty (percent of households), by size of place of residence.

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

**Table 7.** 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%

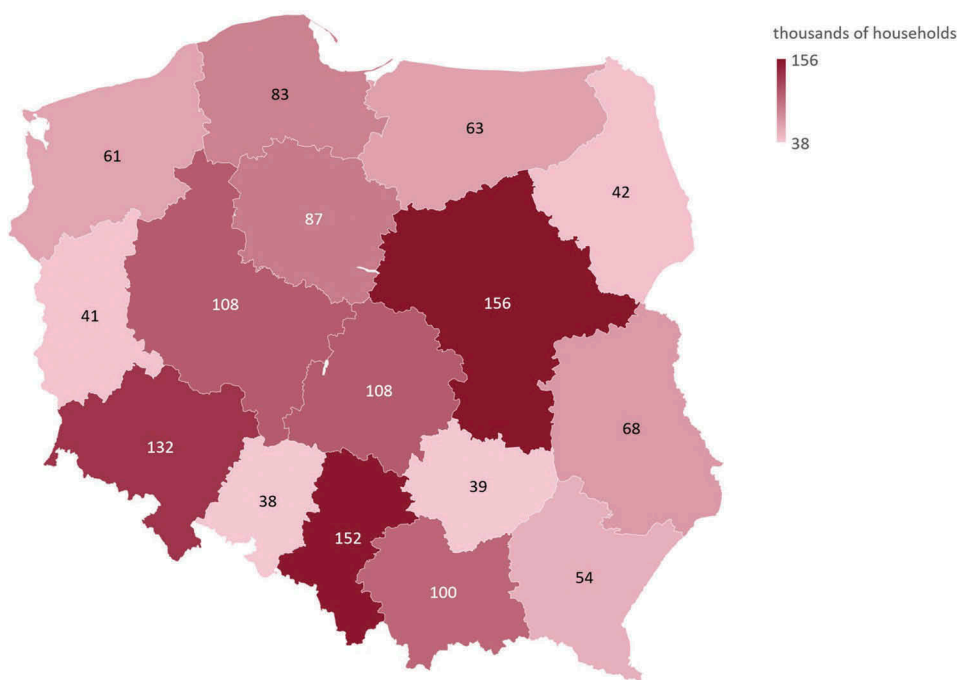Source: Own calculations based on the Household Budget Survey data, 2017.

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, and the share of households living in detached houses are higher. As a result, households living in rural areas represent a higher share 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 7). Households living in large cities represent a lower share among the poor, but they still constitute 27% of all poor households due to their high share in the total population (34%).

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 deprivation, and in particular of home "not being warm enough," is lower in the eastern regions than in the central or western regions (Lis, Miazga, and Sałach 2017).

However, in terms of poverty mapping, 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 (Map 2). The five largest regions (mazowieckie, wielkopolskie, śląskie, małopolskie, dolnośląskie) from 16 voivodships in Poland are home to 49% of all energy-poor households (52% of all households).
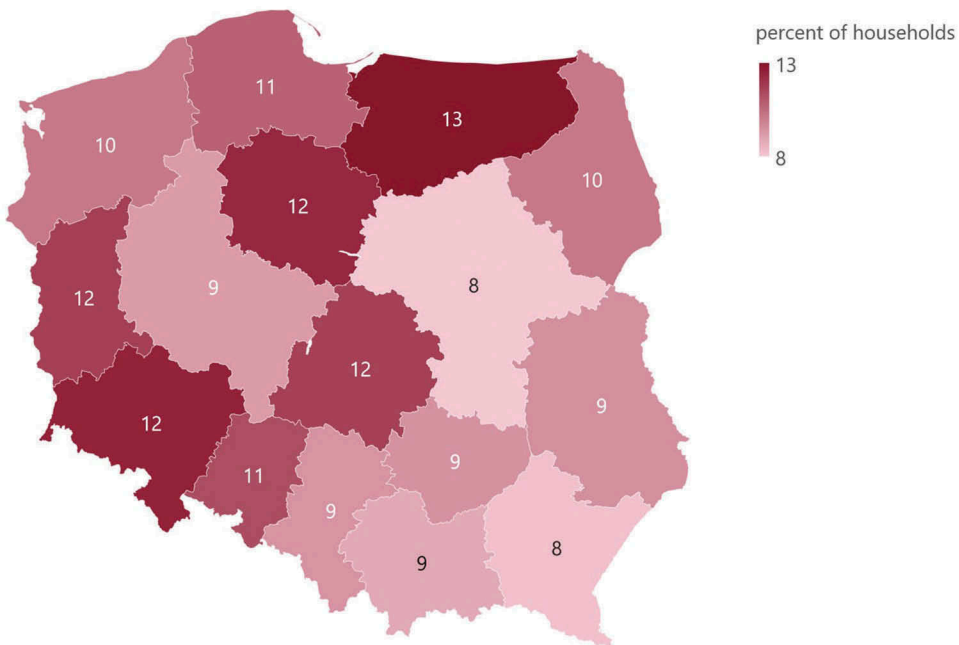
Map 1. Multidimensional energy poverty rate by NUTS2 regions in Poland (percent of households).
Source: Own calculations based on the Household Budget Survey data, 2017.

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.

4.5. Accounting for differences in deprivation intensity

So far we have analyzed the headcount ratio (H) since we have been mainly focused on the differences between the multidimensional index and single indicators. In this subsection, we conduct between-group comparisons accounting for the deprivation intensity (the average number of deprivations among the energy-poor households, "A") and adjusted headcount ratio (M_0). However, 80% of the multidimensionally poor households are deprived in exactly two dimensions, and between-group differences in A are rather small. Hence, we present results only of the most pronounced between-group differences in the deprivation intensity, which are between groups distinguished based on the main sources of income (Table 8). The results for other groups are available upon request.

In 2017, the average energy poverty deprivation intensity in Poland amounted to 2.24, and the adjusted headcount ratio was 0.22. Households living on other non-earned incomes experienced the

Table 8. The headcount, adjusted headcount, and deprivation intensity, by main source of income[8]

	Headcount (H)	Adjusted headcount ratio (M_0)	Deprivation intensity (A)
All households	0.098	0.220	2.24
Blue-collar workers	0.090	0.200	2.22
White-collar workers	0.038	0.082	2.17
Farmers	0.183	0.385	2.11
Self-employed	0.052	0.113	2.15
Retirees and pensioners	0.131	0.295	2.25
Recipients of other non-earned income sources	0.311	0.746	2.40

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

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[8]The detailed results are available upon request.

highest deprivation intensity (2.40) which combined with a high headcount ration (31%) resulted in a much higher adjusted headcount ratio than among other groups. Retirees and pensioners also experienced, on average, more deprivations that the average poor household. On the other hand, farmers, who exhibited the second highest headcount ratio (18.3%) recorded the lowest deprivation intensity (2.11). Households of workers and self-employed exhibited a below-average deprivation intensity. The multidimensional approach shows that households living on non-earned sources of income are more severely affected by energy poverty than it is suggested by particular deprivation measures analyzed independently.

5. Conclusions

In this paper, we have used the Alkire–Foster methodology to develop a multidimensional energy poverty index that allows measuring the coincidence of energy poverty dimensions at a household level. As such, our index differs from previously used compound indices which did not have this feature. We used five indicators of energy deprivation – low income combined with high required costs, high actual energy expenditures, housing defects, inadequate thermal comfort, and difficulties paying utility bills on time – and defined energy-poor households as those that suffer from at least two forms of deprivation. We were able to combine objective and subjective indicators, and at the same time to develop an index that can be used for poverty mapping and policy planning.

We applied our index to Poland, taking advantage of a rich, household-level dataset of the Polish HBS. 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 energy-poor households are income-poor. We have identified three groups that face the greatest risk of multidimensional energy poverty: households that live in buildings built before 1946, households which main source of income is from old-age or disability pension, and households that live in rural areas.

The proposed multidimensional energy poverty index can be useful for policy-makers searching for a detailed understanding of the characteristics of energy-poor households. Households that suffer from multiple types of energy deprivation are likely to be in a worse situation than households affected by only one form of deprivation. Moreover, it offers an easier way to characterize the energy-poor population than particular indicators used independently as the latter may classify different groups as those at the highest risk of deprivation. Hence, the multidimensional index can be particularly useful for targeting public support to households that are most deprived.

According to our knowledge, our article is the first one to use the Alkire–Foster methodology to study energy poverty in a developed country, and using both income/expenditure and self-assessed indicators. We understand, however, its limitations and possibilities for future research. The energy poverty definition to some extent limits it to household characteristics and relies on energy efficiency. Our data allow measuring energy efficiency and energy prices only with proxy indicators, e.g., with subjective thermal comfort and energy expenditures. The use of relative thresholds may impede setting targets for reducing energy poverty. Finally, the indicators are open for refinements in terms of applying a more elaborated conceptual framework.

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Appendix – Methodology of calculating single indicators of energy poverty

    (1) Low income, high costs (LIHC)

A household is classified as energy-poor if it fulfills two criteria simultaneously: a 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.

    Required energy expenditure is calculated based on the actual energy expenditure across households 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 periods).

    The required energy expenditure is the sum of the required expenditure on electricity (the average expenditure on electricity per person multiplied by the number of people in the household in a particular household category) and heat (the average 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 control for the under-occupation of a dwelling which is defined by two conditions: the Parker Morris criterion (based on: DECC 2014) and the Eurostat criterion (based on: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Under-occupied_dwelling).
- For the equivalised required electricity 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 based on two conditions met simultaneously: (i) the equivalent income of a household is in the lowest 30% of incomes in the population, and (ii) the equivalent household income after housing costs is lower than the individual income threshold.

- The equivalent disposable income of households is calculated using 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.
- Income after housing costs equals disposable income less expenditures on water supply and other services, rent, and mortgage payment.
- The equivalisation of income after housing costs is performed using 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 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 costs)

A household is classified as energy-poor if its share of actual energy expenditure in income equals at least double the median of this share in the population.

- Household energy expenditure is the sum of spending on electricity and heat.
- We omit the households in the first income percentile in the calculation of threshold.

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

Indicator 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 classified as energy-poor.

(4) Presence of leaks, damp, or rot (housing faults)

Indicator 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 classified as energy-poor.

(5) Inability to pay utility bills (bills difficulties)

Indicator based on 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 classified as energy-poor.