

Article

Energy Poverty in the Era of Climate Change: Divergent Pathways in Hungary and Jordan

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Abstract

This study examines the interrelated challenges of climate change and energy poverty across two distinct industrial regions: Borsod-Abaúj-Zemplén in Hungary and Zarqa in Jordan. Both areas face unemployment and low-income levels, as well as environmental legacies of industrial activity; however, they differ significantly in their energy policies and infrastructure development. Using 2025 survey data, we develop indices of energy poverty, financial poverty, and climate perceptions, aligned with OECD guidelines. Regression analysis indicates that the model accounts for approximately 40% of the variance in energy poverty. Notably, heightened perceptions of climate change are associated with increased reports of energy hardship, suggesting that economically deprived households possess greater climate risk awareness. Resilience capacities, including adaptive skills, income stability, and community support, are found to substantially mitigate energy poverty. Income and employment status also play protective roles, underscoring the importance of economic resources. The impact of financial poverty varies markedly, being negligible in Hungary but severe in Jordan due to structural and infrastructural constraints. Our findings underscore the need for tailored, inclusive policy interventions that emphasize energy efficiency and retrofitting in Hungary and promote financial support and the adoption of renewable energy in Jordan. Integrating principles of energy justice into climate resilience strategies is crucial for promoting equitable and sustainable energy transitions, mitigating local vulnerabilities, and enhancing overall household resilience.

Keywords: energy poverty; income poverty; climate change; energy transition; global south; global north; comparative analysis



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1. Introduction

Climate change and the energy transition are closely linked to social vulnerability: weather extremes and gradual climatic shifts increase households' exposure to energy-related risks. In contrast, energy system reform and decarbonization can create distributional effects that either worsen or ameliorate energy poverty. Building effective climate resilience necessitates a coordinated focus on energy affordability, access, and system reliability. This challenge is being actively addressed through the innovative approach of Urban Energy Districts (UEDs), which aim to connect technological solutions with social and economic objectives. The Intergovernmental Panel on Climate Change (IPCC) has made clear that climate change is already producing uneven impacts and that adaptation and resilience must be mainstreamed into policy to avoid amplifying existing inequities [1].

Energy poverty is broadly defined as the inability to access and afford materially and socially adequate levels of household energy services [2]. It has evolved from a narrow focus on heating in cold climates into a multidimensional concept encompassing affordability, access to modern fuels, adequacy of housing and appliances, and reliability of supply [3]. Classic treatments of fuel poverty emphasize the combined impact of low income, high energy costs, and poor housing energy performance [4]. Contemporary studies extend that framework to include cooling needs, intermittent supply, and the distributional impacts of energy policy [5–7]. This broadened conceptualization is essential when assessing resilience outcomes because households' capacity to prepare for, cope with, and recover from climate stressors depends on physical infrastructure and household resource endowments.

Accelerating climate change and ongoing energy transitions are transforming household energy systems globally [8]. However, these developments risk exacerbating existing social inequalities if distributional impacts are not sufficiently addressed. Increases in energy prices, heightened demand for cooling and heating, and the implementation of decarbonization policies may disproportionately affect low-income households, thereby intensifying energy poverty [9]. Although research on energy deprivation is expanding, there is still a lack of comparative, household-level evidence that simultaneously considers economic vulnerability, climate perceptions, and resilience capacities across diverse institutional contexts [2,10]. This research gap is especially pronounced in industrial-legacy urban regions, where inefficient housing stock, labor-market instability, and environmental stress converge [11]. Analyzing how these factors interact under varying policy regimes is crucial for developing equitable and climate-resilient urban energy strategies.

Accordingly, this study has three objectives:

- (1) to develop composite indicators that measure energy poverty, financial poverty, and climate perception–resilience within a climate-sensitive framework;
- (2) to empirically analyze the determinants of household energy poverty in two structurally similar but institutionally different regions in Hungary and Jordan; and
- (3) to derive policy-relevant insights for inclusive urban energy transitions, focusing on energy efficiency, resilience building, and social protection.

Although Hungary and Jordan belong to different geopolitical and institutional contexts, they are analytically comparable as cases of semi-peripheral, energy-import-dependent economies facing structurally embedded vulnerabilities in household energy access [2,12]. The basis for comparison in this study is not geographic proximity or political similarity, but the presence of homologous structural conditions: strong dependence on imported fossil fuels, pronounced territorial inequalities between industrial and post-industrial regions, ageing or inefficient housing stocks, and exposure of low-income households to price volatility and climate-related energy stress [13,14].

Hungary represents the dynamics of energy poverty within a highly regulated European welfare and market framework, where historic industrial decline, path-dependent housing inefficiencies, and price regulation coexist [15]. Jordan, in contrast, represents an energy-insecure, import-dependent economy in which rapid urbanization, climatic stress, and policy-driven energy diversification shape household vulnerability [6,16]. Comparing these contexts allows the study to isolate how similar structural risk factors operate under different welfare regimes, institutional capacities, and climatic pressures, thereby strengthening the external validity of the findings beyond a single regional or political setting [17].

This study offers four distinct contributions to the literature on energy poverty and climate change. First, it advances a comparative, micro-level analysis of household energy poverty that explicitly integrates perceptions of climate change and resilience capacities, an aspect that remains underexplored in both the Global North and the Global

South. While previous research has primarily examined energy poverty through the lenses of affordability and access, this study empirically demonstrates how subjective climate awareness and adaptive capacity interact with material deprivation. Second, the study introduces a resilience-sensitive operationalization of energy poverty that combines thermal discomfort, housing-related symptoms such as mold and dampness, and seasonal exposure. This approach aligns energy poverty measurement with contemporary debates in climate adaptation and extends beyond traditional expenditure-based or access-based indicators. Third, by comparing Hungary and Jordan, two energy-import-dependent, semi-peripheral economies embedded in different institutional and welfare regimes, the study demonstrates that financial poverty does not exert a uniform effect on energy deprivation. Instead, its impact is strongly mediated by national energy systems, housing structures, and policy frameworks. These findings challenge universal policy prescriptions and underscore the need for context-specific interventions. Finally, the study contributes to urban energy policy discourse by linking household-level vulnerability to the emerging concept of Urban Energy Districts. The results offer empirical support for designing socially inclusive, climate-resilient urban energy strategies that integrate building performance, social protection, and adaptive capacity.

The remainder of the paper is structured as follows: Section 2 reviews the literature and clarifies the measurement choices, Section 3 presents the data and methods, Section 4 presents the empirical results, and Section 5 concludes with a discussion of limitations and policy recommendations.

2. Literature Review

Energy poverty and financial poverty are closely intertwined with climate change, forming a complex feedback loop that significantly affects vulnerable populations globally. In this section, we discuss the relevant literature on energy poverty and financial poverty.

2.1. Energy Poverty

Energy poverty has emerged in recent years as a significant social, economic, public health, and environmental issue. While global efforts toward electrification have made considerable progress, many households—both in low-income and high-income countries—still lack access to sufficient, affordable, and reliable energy services necessary for basic living standards. As countries confront energy transitions, rising energy prices, climate change, and inequality, the risk of energy poverty becoming more entrenched for vulnerable populations is increasing.

Energy poverty is multidimensional. It concerns not only whether a household is connected to electricity or has a stove, but also whether energy is affordable, whether the dwelling is sufficiently insulated to reduce energy use, whether the energy supply is reliable, and so on. It refers to the lack of access to modern energy services or the inability to afford adequate energy for basic needs such as heating, cooling, lighting, and communication. The specific deprivations may vary across many low-income and rural countries; a lack of access to clean cooking fuels and electricity is a primary one. In more developed countries, the challenge may be high bills, inefficient housing, or inadequate thermal comfort [14].

Although Hungary and Jordan differ markedly in climate, welfare systems, and energy infrastructure, each faces distinct forms of energy poverty. In Hungary, the issue is heavily influenced by the poor thermal performance of the housing stock—many detached homes and rural buildings exhibit low energy efficiency, inadequate insulation, and windows. These factors, combined with affordability constraints, contribute to the difficulty in heating and, in some cases, cooling [11,18,19].

In both countries, income and energy prices are strong determinants: low-income households are more vulnerable to price shocks, struggle with the costs of energy or housing upgrades, and are at risk of arrears or resort to coping behaviors (e.g., rationing, underheating, undercooling). In Hungary, many poorer households use solid fuels or lower-quality heating methods and are more exposed to inefficiencies of dwellings [11,19]. In Jordan, owning cooling appliances, type of fuel, dwelling type, etc., significantly affect whether a household is energy poor [20].

The poor energy efficiency of dwellings increases energy demand for comfort in both contexts (heating in winter and cooling in summer), making households with inefficient housing more vulnerable. Multidimensional frameworks emphasize that energy poverty arises from the interplay of technical, infrastructural, socioeconomic, and environmental constraints, rather than from a single factor. For Jordan, this is explicitly captured by its composite energy poverty index (housing, fuel, cooling, wealth [20]. For Hungary, too, technical housing conditions (insulation, window quality) plus affordability are central [19].

A Hungarian-specific driver is the age and quality of the housing stock, as well as regulatory and market settings for household energy, and rural–urban differences. Many Hungarian homes have insufficient insulation, aging heating systems, and legacy building designs that result in high heat losses, which in turn increase the energy required to maintain thermal comfort and exacerbate affordability problems, even where nominal tariffs are moderate. NGO modelling and JRC microdata analyses emphasize that different measures (expenditure thresholds vs. self-reported inability to keep warm) identify different at-risk groups, complicating policy targeting [21].

Jordan's energy poverty stems from efficiency deficits, climate-related cooling demand, limited access to clean cooking in specific communities, and structural and demographic pressures. Rapid urbanization, high summer cooling needs, and a reliance on specific fuel types for cooking or heating create distinct demands. While grid access is widespread, service quality, appliance ownership patterns, and household finances shape the deprivation measures used by MEPI. Studies indicate that energy poverty in Jordan is spatially heterogeneous and correlated with the governorate, urban-rural status, and wealth [3,20].

Both countries face environmental consequences in which inefficient energy use increases aggregate demand and emissions (and, where traditional biomass is still used, indoor/outdoor air pollution is a problem). These health–welfare links are well-documented in the energy-poverty literature and country studies [3].

2.2. Financial Poverty

Financial poverty exacerbates energy poverty by limiting households' economic capacity to access sufficient energy, thereby intensifying household hardships. Financial poverty, broadly defined, refers to the condition in which individuals or households lack enough monetary resources to meet the minimum standards of living, including access to adequate food, shelter, healthcare, and education [22]. While often used interchangeably with economic deprivation, financial poverty is a narrower construct that focuses on income and expenditure shortfalls, distinguishing it from broader notions of multidimensional poverty, which include social exclusion, housing quality, and access to basic services [23].

The most widely used measure of financial poverty is the income poverty line, often set at \$1.90 per day in 2017 purchasing power parity (PPP) terms for international comparison [22]. This threshold denotes the minimum income required to meet basic needs in low-income countries. However, many scholars argue that such a single global line is too simplistic, as it fails to capture regional differences in the cost of living and social expectations [24]. To address this, middle-income thresholds (e.g., \$3.20 and \$5.50/day PPP) are often applied. In high-income countries, relative poverty lines—such as 60% of the median

national income—are more common, reflecting societal standards and considerations of inequality [25]. Absolute and relative poverty lines do not account for the psychological dimension of well-being, even though this aspect is vital for understanding poverty and developing effective strategies to address it. For these reasons, the subjective poverty concept has been created, which highlights people's own perceptions of their economic situation [26,27].

Household expenditure surveys are another crucial source for assessing financial poverty, particularly in areas where informal economies prevail and incomes are underreported. Complementary approaches include consumption-based measures, which better reflect long-term welfare than income alone, since they account for savings, transfers, and coping strategies [28].

Financial poverty arises from a combination of structural and individual factors. Structural determinants include macroeconomic instability, unemployment, labor market segmentation, and systemic inequality in the distribution of wealth and opportunities [29]. For example, households headed by individuals with limited education are more likely to face persistent financial poverty due to lower earning potential and restricted access to skilled labor markets. At the same time, shocks such as illness, natural disasters, or conflict can push non-poor households into transient poverty [30]. In both developed and developing contexts, weak social safety nets exacerbate vulnerability by failing to buffer income losses or rising living costs.

Financial poverty has profound implications for health, education, and social mobility. Poor households often face barriers to accessing adequate nutrition, clean water, and medical services, which perpetuate cycles of ill health and reduced productivity [31]. In education, financial constraints limit school attendance, especially among children in low-income families, reinforcing intergenerational poverty traps. Moreover, lack of financial resources restricts participation in formal financial systems, such as savings and credit markets, thereby curtailing opportunities for investment in human and physical capital [32].

Beyond material deprivation, financial poverty also intersects with psychological stress and social exclusion. Research shows that a scarcity of financial resources can impair cognitive decision-making, leading to suboptimal economic choices and reinforcing the persistence of poverty [33]. Relative poverty, even where absolute needs are met, contributes to diminished social cohesion and higher inequality, with adverse effects on societal well-being [34].

Addressing financial poverty requires multifaceted strategies. Direct income support, such as cash transfer programs, is effective in reducing short-term poverty and improving child welfare indicators in many regions [35]. Long-term strategies include investments in education, job creation, and health infrastructure to build human capital and resilience. Additionally, inclusive financial systems that expand access to credit and savings opportunities are critical for enabling upward mobility. Policymakers increasingly recognize the importance of combining poverty alleviation with inequality reduction to ensure sustainable and equitable growth [36].

While both Jordan and Hungary are classified as middle-income economies by the World Bank, their poverty profiles differ in scale, nature, and trajectory. The Hungarian average income level has been 2–3 times higher than the Jordanian one for long decades (see Figure 1). In Hungary, poverty is generally measured using the at-risk-of-poverty indicator, defined as the share of people with equivalized disposable income below 60% of the national median. According to Eurostat, approximately 14.5% of the Hungarian population fell into this category in 2023 [37]. This relative measure highlights inequalities within Hungarian society rather than absolute deprivation. Vulnerable groups include

unemployed people, of whom nearly 47.3% were at risk of poverty, as well as single-parent households and elderly individuals living alone [37,38].

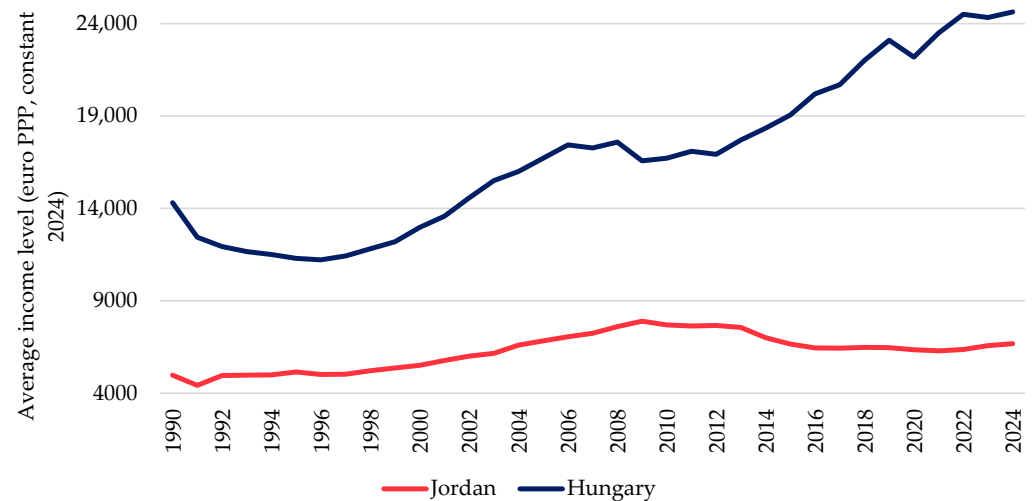


Figure 1. Average income level in Hungary and in Jordan, 1990–2024, Euro PPP. Source: own compilation based on data from World Inequality Database.

By contrast, Jordan uses a national poverty line based on the minimum cost of basic goods and services, which, in recent estimates, corresponds to approximately USD 7.90 per day (PPP). The World Bank and Jordan’s Department of Statistics report that approximately 35% of Jordanians currently live below this threshold [39,40]. This represents a sharp increase from earlier estimates of 24% in 2021, primarily attributed to inflationary pressures, rising food and energy costs, and economic shocks linked to the COVID-19 pandemic [39].

Trends also diverge. Hungary experienced a moderate decline in poverty risk during the mid-2010s; however, rising inflation and energy price volatility since 2021 have increased financial pressures on households [41]. In Jordan, poverty trends have worsened more sharply: international reports emphasize that poverty has deepened in the wake of multiple crises, including global fuel price spikes, food import dependency, and structural unemployment [40].

2.3. Theoretical Framework

Climate change intensifies the challenges of energy poverty and financial poverty through multiple pathways. Climate policies aimed at reducing greenhouse gas emissions often increase energy costs, particularly for electricity generated from fossil fuels. Stringent climate regulations can lead to higher electricity prices, which disproportionately affect low-income and energy-poor households, thereby increasing the risk of deeper energy poverty [42]. In developing countries with limited infrastructure and weaker social protection schemes, climate policies without accompanying supportive measures may significantly exacerbate energy poverty [42].

Climate change is increasingly affecting energy demand by altering temperature patterns. Rising temperatures intensify the need for cooling in summer, whereas extreme cold events can still increase heating demand in winter. For example, Ref. [43] shows that future climatic changes significantly increase building cooling loads, while Ref. [44] highlights how climate change affects heating and cooling demand, depending on the building envelope’s characteristics. Similarly, studies of heating and cooling degree days in China demonstrate that shifting climatic conditions directly impact household energy consumption [45]. These rising energy needs also translate into higher costs, which disproportionately burden low-income households already struggling financially [46].

Evidence suggests that the effects of climate change exacerbate poverty traps stemming from energy and financial poverty. Climate shocks, such as floods and droughts, destroy assets and livelihoods, pushing more people into poverty or preventing them from escaping it [10]. Higher energy prices and food costs—both vulnerable to climate impacts—reduce disposable incomes among people experiencing poverty, limiting their ability to improve well-being [10,47].

However, climate policies can also reduce energy poverty by promoting access to renewable energy and improving energy efficiency. Subsidies and green finance mechanisms can facilitate renewable energy innovation, supporting low-carbon electrification and reducing energy poverty, particularly in marginalized rural areas [48].

3. Data and Methodology

3.1. Study Area

This study compares two distinct contexts worldwide. On the one hand, Borsod-Abaúj-Zemplén County is located in Hungary, a part of the European Union. On the other hand, Zarqa is located in Jordan in the Middle East. The logic of comparability in this study is anchored in structural and socio-economic positioning rather than geographic or cultural similarity. Both Borsod-Abaúj-Zemplén and Zarqa can be classified as industrial-legacy regions located outside national growth cores, with relatively weak labor markets, elevated unemployment risks, and long-term environmental burdens from heavy industry [12]. Both regions exhibit energy system vulnerabilities, characterized by inefficient building stock, constrained household purchasing power, and heightened sensitivity to energy price shocks [2,14]. These shared structural features provide a coherent analytical foundation for systematic comparison despite differences in governance regimes and macro-regional location.

3.2. Data Collection

Our study is based on primary data collected through a survey. We developed our survey questions, dividing them into three main sections and a fourth section on demographics. The survey comprised 30 questions and took approximately 10 min to complete after consulting experts and testing a demonstration sample. Questions were mainly based on the reviewed literature on climate change resilience and energy poverty [49–51]. We conducted the study in Hungarian in Hungary and in Arabic in Jordan, using convenience sampling, and made the survey available online for one month, from March to April 2025. We received 221 responses from Borsod-Abaúj-Zemplén and 218 from Zarqa. To ensure data validity, we checked for false responses and invalid entries. We acknowledge that our data collection method is non-probabilistic; therefore, the results should be interpreted with caution. However, as this is an exploratory study, we will analyze the results based on the sample we collected. Table 1 shows more details on the sample composition and demographics.

The sample from Borsod-Abaúj-Zemplén ($n = 221$) is predominantly female (71.0%), with men accounting for 29.0%. A majority of respondents (57.0%) reside in urban areas, while 43.0% live in rural settings. In terms of educational attainment, very few reported having no education (0.5%) or only primary schooling (1.4%), whereas one-third had completed secondary education (34.4%) and almost two-thirds held tertiary qualifications (63.8%). Employment patterns indicate that most participants are employed full-time (70.1%), with smaller proportions reporting part-time employment (4.1%), public employment (3.2%), retirement (7.2%), or unemployment (2.3%). Other categories, such as dependency (3.6%), self-employment (3.2%), and miscellaneous forms of work (5.9%), account for the remainder.

Table 1. Composition of Hungarian and Jordanian samples.

	Variable	Borsod-Abaúj-Zemplén (n = 221)	Zarqa (n = 218)
Gender	Male	29.0%	31.7%
	Female	71.0%	68.3%
Area	Urban	57.0%	82.1%
	Rural	43.0%	17.9%
Education	None	0.50%	0.00%
	Primary education	1.40%	6.40%
	Secondary education	34.4%	24.8%
	Tertiary education	63.8%	68.8%
Employment status	Full time	70.1%	21.1%
	Part-time	4.10%	7.30%
	Contract or temporary	0.50%	3.20%
	Public employment	3.20%	12.4%
	Retired	7.20%	8.70%
	Unemployed	2.30%	22.5%
	Dependent	3.60%	3.20%
	Self-employed	3.20%	5.00%
	Other	5.90%	16.5%

The Zarqa sample (n = 218) also consists primarily of women (68.3%), with men comprising 31.7%. Urban residents form the overwhelming majority (82.1%), compared to 17.9% in rural areas. Educational attainment is relatively high: 68.8% of respondents hold a tertiary qualification, 24.8% hold a secondary qualification, and 6.4% hold a primary qualification; none reported having no formal education. Employment distribution differs considerably from that in Borsod: only about one-fifth (21.1%) are employed full-time, whereas a substantial share (22.5%) is unemployed. Other employment statuses include part-time work (7.3%), contract or temporary positions (3.2%), public employment (12.4%), retirement (8.7%), dependency (3.2%), self-employment (5.0%), and a sizable proportion in the “other” category (16.5%). Taken together, the two samples share similarities in their gender and educational profiles but differ markedly in their employment structures and urban–rural compositions.

3.3. Statistical Analysis

3.3.1. General Approach to Composite Construction

Composite indicators were developed using a systematic approach [52]. The process began with the identification of relevant survey questions for each construct. Next, categorical and Likert-scale responses were converted into numerical codes and aligned to ensure consistent interpretation, with higher scores indicating greater poverty-related deprivation and stronger awareness or resilience for climate constructs. If necessary, scales were standardized to facilitate comparisons across items. The coded items were then combined through summation or averaging, depending on the item structure. Lastly, internal consistency and construct validity were evaluated using reliability tests (e.g., Cronbach’s alpha) and logical cross-checks with related variables, such as income or equipment use.

3.3.2. Composite Energy Poverty Indicator

Energy poverty was defined as having inadequate access to comfortable indoor temperatures and poor housing conditions. We chose five survey items: how comfortable you feel in winter and summer (binary), how hot or cold you think it is in winter and summer (seven-point ordinal), and whether you have mold or dampness (binary). We coded the responses such that higher values indicated greater energy-related deprivation. For ease of interpretation, we coded 0 as ‘comfortable’ and 1 as ‘uncomfortable’. For temperatures, we recorded the distance from neutral, with values ranging from 0 (neutral or comfortable) to 3 (extremely uncomfortable), using the absolute value of the deviation from the midpoint. Mold or dampness was coded as 0 for absent and 1 for present. We then combined these items into a household-level index:

$$\text{Energy Poverty Score} = \text{Winter Comfort} + \text{Summer Comfort} + \text{Winter Discomfort} + \text{Summer Discomfort} + \text{Mold/Dampness} \quad (1)$$

The resulting index scores range from 0 (no energy-related deprivation) to 9 (maximum deprivation). Although the items combine binary and ordinal scales, they are conceptually consistent, and the summative approach allows for comparisons across households. To ensure validity, we examined correlations between the composite and related indicators, such as household income and reliance on heating and cooling equipment.

3.3.3. Composite Financial Poverty Indicator

Financial poverty was measured by asking about household financial struggles and instability. We selected five Likert-scale items (1–5) assessing perceived financial situation, difficulty affording basic needs, frequency of borrowing, financial stability, and financial comparison to others. To ensure directional consistency, all items were recoded such that higher values indicated greater financial poverty. For instance, self-assessed financial situation (1 = very poor, 5 = very good) was reversed to align with this convention. After recoding, all items shared a 1–5 scale. The composite score was calculated as the arithmetic mean of the five items.

3.3.4. Composite Climate Change Perceptions and Resilience Indicator

Climate change was examined through two interconnected aspects: perceptions, encompassing beliefs and concerns, and resilience, defined as the capacity to adapt and community support. We used eight Likert-scale questions (1–5) to assess these aspects, covering topics such as belief in climate change, attribution of climate change to human activity, concern about its effects, and expectations of changes in livelihoods and energy use. We also inquired about the extent to which households can adapt, how climate change affects poorer communities, and whether community support systems are in place to address these issues.

All questions were scored such that higher scores indicated greater awareness and resilience. Since the questions were already on the same scale, we did not need to adjust them. We then created a composite indicator by averaging the responses to the eight questions. This indicator ranges from 1 (low awareness/resilience) to 5 (high awareness/resilience). To ensure the questions were reliable, we analyzed them both together and separately for perceptions (five questions) and resilience (three questions), and made further adjustments as needed.

To examine the determinants of household energy poverty, multiple linear regression models were estimated [53]. The dependent variable is the composite Energy Poverty Score (EP_i), constructed as described earlier. The core independent variables, reflecting the study’s conceptual framework, include financial poverty (FP_i), climate perceptions (CP_i),

and climate resilience (CR_i). These variables capture economic vulnerability, experiential awareness of climate-related stress, and households' adaptive capacity, respectively.

To account for contextual differences between the two study regions, a region dummy variable was included in the pooled model ($Region_i = 0$ for Zarqa, 1 for Borsod-Abaúj-Zemplén). In addition, region-specific regression models were estimated separately for Zarqa and Borsod-Abaúj-Zemplén to assess heterogeneity in the magnitude and significance of predictors across contexts. This two-step strategy allows for both an overall assessment of regional effects and a more detailed examination of place-specific dynamics without imposing interaction effects a priori.

The general form of the pooled model is

$$EP_i = \beta_0 + \beta_1 CP_i + \beta_2 CR_i + \beta_3 FP_i \times \beta_4 Region_i + \varepsilon_i \quad (2)$$

where the following definitions are used:

EP_i = energy poverty score of household i ;

CP_i = climate change perception score;

CR_i = climate resilience score;

FP_i = Financial Poverty Score;

$Region_i$ = regional dummy (0 = Zarqa, 1 = Borsod-Abaúj-Zemplén);

β_0 = constant term;

β_1 – β_5 = estimated coefficients;

ε_i = error term.

The regression models were estimated using ordinary least squares (OLS). Model adequacy was assessed using the coefficient of determination (R^2 and adjusted R^2) and the omnibus F-test. Multicollinearity was evaluated using variance inflation factors (VIFs), all of which remained below conventional thresholds.

To assess robustness, extended region-specific models that included additional sociodemographic controls (age, gender, educational attainment, and household income) were estimated. These models yielded substantively similar patterns for the core predictors, indicating that model specification choices do not drive the main findings.

4. Results

4.1. Descriptive Analysis of the Main Components

Table 2 provides descriptive statistics for the primary analytical variables by region. Notable differences are evident between the two study areas. The mean level of energy poverty is significantly higher in Borsod-Abaúj-Zemplén (mean = 5.45) than in Zarqa (mean = 2.62), indicating greater energy deprivation in the Hungarian context. Financial poverty is also more pronounced in Borsod. Both regions report high levels of perceived climate, with Zarqa exhibiting slightly higher average levels. Climate resilience shows similar means across regions, although greater variability is observed in Zarqa. These descriptive findings inform the subsequent multivariate analysis, which investigates the determinants of energy poverty and the influence of contextual factors.

Table 2. Descriptive statistics of key variables by region.

County		Minimum	Maximum	Mean	Std. Deviation
Zarqa	<i>EP</i>	0.000	9.000	2.620	2.143
	<i>FP</i>	1.000	4.800	2.186	0.619
	<i>CP</i>	1.000	5.000	4.002	0.712
	<i>CR</i>	1.000	5.000	3.519	0.728

Table 2. Cont.

County		Minimum	Maximum	Mean	Std. Deviation
Borsod-Abaúj-Zemplén	EP	0.000	9.000	5.450	2.695
	FP	1.000	5.000	3.190	0.993
	CP	1.400	5.000	3.911	0.597
	CR	2.000	5.000	3.593	0.627

4.2. Multiple Linear Regression

Table 3 presents the results of the final pooled linear regression model examining the determinants of household energy poverty. The model exhibits substantial explanatory power (adjusted $R^2 = 0.392$) and achieves overall statistical significance ($F = 71.69$, $p < 0.001$).

Table 3. Determinants of energy poverty.

Predictor	B	SE (B)	β	t	p	VIF
(Constant)	1.183	0.822	—	1.439	0.151	—
CP	0.358	0.170	+0.084	2.109	0.036	1.140
CR	−0.661	0.168	−0.160	−3.931	<0.001	1.189
FP	1.065	0.131	+0.366	8.147	<0.001	1.453
Region (1 = Borsod, 0 = Zarqa)	1.842	0.251	+0.328	7.354	<0.001	1.433

Financial poverty is the strongest predictor of energy poverty ($B = 1.065$, $\beta = 0.366$, $p < 0.001$), indicating that households with greater economic hardship experience substantially higher levels of energy deprivation. Climate resilience is significantly negatively associated with energy poverty ($B = -0.661$, $\beta = -0.160$, $p < 0.001$), indicating that adaptive capacity and perceived community support reduce energy-related vulnerability.

Climate perceptions are positively and significantly associated with energy poverty ($B = 0.358$, $\beta = 0.084$, $p = 0.036$), demonstrating that households experiencing energy hardship report greater awareness of climate change impacts. Region of residence remains a strong and statistically significant predictor ($B = 1.842$, $\beta = 0.328$, $p < 0.001$). Based on the variable coding (0 = Zarqa, 1 = Borsod-Abaúj-Zemplén), households in the Hungarian study region experience significantly higher levels of energy poverty than those in Zarqa, after controlling for financial poverty, climate perceptions, and resilience.

4.3. Region-Specific Regression Analysis

To assess whether the determinants of energy poverty vary across contexts when a broader set of socio-demographic characteristics is considered, separate regression models were estimated for Zarqa and Borsod-Abaúj-Zemplén. These models included age, gender, educational attainment, and household net monthly income in addition to the core predictors. The results are summarized in Table 4.

Table 4. Region-specific regression models with extended socio-demographic controls.

Predictor	Zarqa (B)	Zarqa (SE)	Zarqa (β)	p	Borsod (B)	Borsod (SE)	Borsod (β)	p
CR	−0.709	0.205	−0.241	0.001	−0.544	0.280	−0.127	0.053
CP	0.244	0.207	0.081	0.240	0.684	0.290	0.152	0.019
FP	0.456	0.270	0.132	0.093	1.260	0.220	0.464	<0.001
Household net monthly income	−0.184	0.108	−0.137	0.090	0.018	0.103	0.015	0.859

Table 4. Cont.

Predictor	Zarqa (B)	Zarqa (SE)	Zarqa (β)	<i>p</i>	Borsod (B)	Borsod (SE)	Borsod (β)	<i>p</i>
Gender	0.448	0.295	0.095	0.131	−0.116	0.352	−0.020	0.743
Age	−0.022	0.010	−0.141	0.028	0.006	0.015	0.024	0.706
Educational level	−0.505	0.282	−0.127	0.075	0.219	0.308	0.049	0.478
Constant	6.209	1.463	—	<0.001	−0.109	1.844	—	0.953

Both extended models are statistically significant (Zarqa: $F = 7.43$, $p < 0.001$; Borsod: $F = 10.01$, $p < 0.001$). The explanatory power of these models increases modestly compared to the parsimonious specifications, with adjusted R^2 values of 0.170 for Zarqa and 0.225 for Borsod. These findings indicate that socio-demographic characteristics explain additional variance in energy poverty, particularly in the Hungarian context.

4.3.1. Zarqa

In Zarqa, climate resilience remains a strong and statistically significant predictor of energy poverty ($B = -0.709$, $\beta = -0.241$, $p = 0.001$), underscoring the importance of adaptive capacity and social support in reducing energy deprivation. Age is also significantly negatively associated with energy poverty ($B = -0.022$, $\beta = -0.141$, $p = 0.028$), indicating that younger households are more likely to experience energy hardship. This pattern may reflect life-cycle effects or housing instability.

Financial poverty and household income show marginal associations with energy poverty ($p < 0.10$), whereas climate perceptions are not statistically significant after controlling for socio-demographic characteristics. Gender and educational attainment do not exhibit significant effects. Overall, the Zarqa model indicates that resilience and demographic factors, particularly age, play a more prominent role than climate perceptions in shaping energy poverty outcomes.

4.3.2. Borsod-Abaúj-Zemplén

In Borsod-Abaúj-Zemplén, financial poverty is the primary determinant of energy poverty ($B = 1.260$, $\beta = 0.464$, $p < 0.001$), with a much larger standardized effect than in Zarqa. Climate perceptions also remain positively and significantly associated with energy poverty ($B = 0.684$, $\beta = 0.152$, $p = 0.019$), suggesting greater climate awareness among energy-vulnerable households in this region.

Climate resilience remains negatively associated with energy poverty but is only marginally significant ($p = 0.053$), suggesting that structural housing and infrastructure conditions may constrain the protective role of resilience. Household income, age, gender, and educational attainment do not significantly predict energy poverty in the Borsod model. These results indicate a context in which economic constraints and exposure-related perceptions predominate, whereas individual socio-demographic characteristics play a more limited role.

5. Discussion

This study examined the determinants of household energy poverty in two industrial-legacy urban regions, Zarqa in Jordan and Borsod-Abaúj-Zemplén in Hungary, by integrating economic vulnerability, perceptions of climate, and resilience capacities within a comparative framework. Pooled and region-specific regression analyses revealed both common drivers of energy poverty and significant contextual differences in how these drivers operate across institutional and climatic settings.

5.1. Financial Poverty as a Structural Driver of Energy Poverty

Financial poverty is the most consistent and powerful predictor of household energy poverty across all model specifications. In the pooled analysis, financial hardship demonstrates the largest standardized effect, and this relationship remains strong and highly significant in both regional models, particularly in Borsod-Abaúj-Zemplén, where the association is substantially larger. These findings reinforce a central insight from the energy poverty literature: inadequate financial resources are a necessary condition for energy deprivation, regardless of regional context [2,54,55].

The stronger effect of poverty observed in the Hungarian case aligns with previous research on post-socialist and industrial-legacy regions, where aging housing stock, inefficient heating systems, and exposure to cold climates amplify the material consequences of economic disadvantage [17,56]. After controlling for household income and other sociodemographic factors, financial poverty remains the dominant predictor, underscoring the limitations of income-based measures alone in capturing energy-related vulnerability.

5.2. The Mitigating Role of Climate Resilience

In addition to economic constraints, the analysis identifies climate resilience as a key mitigating factor in household energy poverty. In the pooled model, higher levels of resilience, reflecting adaptive capacity, coping strategies, and perceived community support, are associated with significantly lower energy poverty. This protective effect is particularly pronounced in Zarqa, where the association remains statistically significant even after controlling for age, income, education, and gender.

These findings are consistent with a growing body of research emphasizing the social and relational dimensions of energy vulnerability. Studies indicate that households' ability to cope with energy stress depends not only on income but also on access to social networks, institutional support, and adaptive practices [57,58]. In warmer-climate contexts such as Zarqa, where energy needs are more flexible and housing conditions are more heterogeneous, household-level resilience appears to provide a more effective buffer against energy deprivation.

In contrast, the weaker, only marginally significant effect of resilience in Borsod-Abaúj-Zemplén suggests that structural and infrastructural conditions constrain individuals' coping capacities. In contexts characterized by housing inefficiency, centralized heating systems, and cold climatic conditions, household resilience alone is insufficient to offset high energy demands. These findings support arguments that resilience-based interventions must be complemented by structural investments in housing and energy infrastructure, particularly in cold-climate urban regions [59].

5.3. Climate Perceptions as an Outcome of Lived Energy Hardship

A key contribution of this study is its treatment of climate perceptions as an experiential dimension of energy poverty rather than as a solely attitudinal variable. In the pooled model, climate perceptions are positively associated with energy poverty; this association remains significant in the Borsod-specific models but not in Zarqa after additional controls are introduced.

This pattern suggests that heightened climate awareness among energy-poor households reflects direct exposure to thermal discomfort, inefficient housing, and extreme weather conditions rather than abstract environmental concern. Prior research has shown that climate change perceptions are often grounded in everyday material experiences, particularly among vulnerable populations facing heat stress, cold exposure, or unreliable energy access [60]. The stronger association observed in Borsod likely reflects the salience of cold-related energy stress and heating insecurity in shaping climate awareness.

The absence of a significant relationship in Zarqa after accounting for socio-demographic factors indicates contextual variation in how climate change is experienced and interpreted. In lower-income, warmer-climate settings, perceptions of climate are likely shaped more by broader societal discourse and indirect environmental stressors than by household-level energy deprivation alone.

5.4. Contextual Heterogeneity and the Limits of One-Size-Fits-All Policy

The significant regional effect identified in the pooled model, together with divergent patterns in region-specific analyses, emphasizes the necessity of place-based approaches to energy poverty. Even after accounting for financial poverty, resilience, and perceptions of climate, households in Borsod-Abaúj-Zemplén exhibit substantially higher levels of energy poverty than those in Zarqa. This result underscores the influence of contextual factors, including housing stock quality, climatic exposure, energy infrastructure, and policy regimes, in shaping energy vulnerability [13].

The extended regional models further indicate that socio-demographic characteristics interact with energy poverty in context-specific ways. For example, age effects are present in Zarqa but absent in Borsod, whereas education and income become weak predictors once financial poverty is controlled for. These distinctions caution against universal policy prescriptions and instead highlight the need for differentiated strategies that address local housing conditions, climatic risks, and social structures.

5.5. Policy Implications

Collectively, the findings indicate that effective mitigation of energy poverty necessitates a combination of economic, social, and structural interventions. Income support and affordability measures are essential, particularly in regions where financial poverty is the primary driver of energy deprivation. Additionally, policies that enhance household and community resilience, such as social support programs, energy advisory services, and adaptive housing measures, can serve as critical complements, especially in warmer-climate and lower-income contexts.

In colder, industrial-legacy regions such as Borsod-Abaúj-Zemplén, the results point to the need for structural solutions, including housing renovation, heating system modernization, and energy-efficiency investments. Without addressing these underlying infrastructural constraints, household-level resilience strategies are likely to have limited impact.

6. Conclusions and Policy Implications

This study investigated the determinants of household energy poverty in two industrial-legacy urban regions, Zarqa in Jordan and Borsod-Abaúj-Zemplén in Hungary, using a comparative framework that integrates financial poverty, perceptions of climate, and resilience capacities. By employing both pooled and region-specific regression analyses, this research provides new empirical evidence on the influence of household-level vulnerabilities and contextual factors in shaping energy poverty.

The findings indicate that financial poverty is the most influential and consistent determinant of energy poverty across both regions. Nevertheless, economic vulnerability alone does not fully account for energy deprivation. Climate resilience significantly mitigates energy poverty, particularly in Zarqa, underscoring the importance of adaptive capacity and social support in alleviating household energy stress. Additionally, the observed association between climate perceptions and energy poverty, especially in the Hungarian region, suggests that climate awareness among vulnerable households is closely related to direct experiences of thermal discomfort and exposure rather than to abstract environmental concerns.

A principal contribution of this research is its comparative perspective. After controlling for household characteristics, energy poverty remains significantly higher in Borsod-Abaúj-Zemplén than in Zarqa, underscoring the critical role of structural and infrastructural factors, including housing stock quality, climatic exposure, and energy systems. The region-specific analyses further demonstrate that the mechanisms linking climate, resilience, and energy poverty vary across institutional contexts, underscoring the need for place-based analytical and policy approaches.

From a policy standpoint, the results indicate that effective mitigation of energy poverty necessitates a combination of income support, resilience-building interventions, and structural investments. Financial assistance and affordability measures are essential, particularly in economically disadvantaged regions. However, policies that strengthen household and community resilience may be particularly effective in warmer-climate and lower-income settings. In contrast, in colder, industrial-legacy regions, structural interventions focused on housing renovation, energy efficiency, and heating systems are likely to be crucial.

This study is subject to several limitations. The reliance on cross-sectional survey data restricts causal inference and limits the capacity to capture dynamic changes in energy vulnerability over time. Furthermore, the measurement of climate perceptions and resilience is based on self-reported indicators, which may introduce reporting bias. Future research should consider employing longitudinal designs, incorporating objective measures of housing and energy performance, and expanding comparative analyses to additional regions and institutional contexts.

In conclusion, this study advances understanding of energy poverty by demonstrating that it is a multidimensional, context-dependent phenomenon at the intersection of economic vulnerability, climate exposure, and adaptive capacity. Addressing energy poverty in the context of climate change requires integrated, place-sensitive strategies that extend beyond income-based solutions and consider the lived experiences of vulnerable households.

Study Limitations

This study has several limitations that constrain the scope of inference. First, the analysis is based on cross-sectional survey data, which limits the ability to draw causal conclusions about the relationships among financial poverty, climate perceptions, resilience, and energy poverty. Although robust associations are observed, longitudinal data would be necessary to investigate temporal dynamics and feedback mechanisms.

Second, key constructs such as climate perceptions and climate resilience are assessed using self-reported indicators. While these measures reflect lived experiences and adaptive capacities, they may be subject to individual interpretation. Future research should supplement survey-based measures with objective indicators, such as housing energy performance, energy consumption records, or localized climate exposure data.

Third, the comparative design centers on two industrial-legacy urban regions rather than nationally representative samples. While this place-based approach enables detailed contextual analysis, the findings should be viewed as indicative of broader processes in comparable urban and post-industrial settings, rather than as universally generalizable patterns. Applying the framework to additional regions would enhance the potential for comparative generalization.

Finally, although the primary analysis employs parsimonious, theory-driven regression models, extended specifications that incorporate additional socio-demographic controls produce substantively similar results. This indicates that the core findings are robust to alternative model specifications. Future research could employ multilevel or longitudinal modeling to further distinguish household- and context-level influences.

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