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HOUSEHOLD-LEVEL ENERGY POVERTY ASSESSMENT IN IRELAND: A COMPARATIVE ANALYSIS OF INDICATOR-BASED APPROACHES

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Abstract

Energy poverty measurement at the household level is sensitive to indicator choice and data availability. This study evaluates energy poverty in Dublin using a set of expenditure-based, income-sensitive, and needs-based indicators with a Building Energy Rating (EPC) dataset. Household income uncertainty is addressed through scenario-based income assumptions, enabling estimation of indicator-specific thresholds and escape income levels. Results reveal divergence in household classification across indicators, driven largely by structurally high energy costs linked to dwelling characteristics. The findings highlight the limitations of single-indicator approaches and demonstrate the value of comparative, household-level frameworks for informing targeted energy poverty interventions in data-constrained contexts.

Introduction

Energy poverty is increasingly recognised as a multidimensional condition arising from the interaction of low household income, high energy costs, and poor dwelling energy efficiency, which together restrict access to essential domestic energy services. This concept extends beyond traditional fuel poverty that focuses primarily on heating affordability, and instead encompasses the broader set of energy services required for an acceptable standard of living, including space heating, water heating, lighting, and appliance use (Boardman 1991; González-Eguino 2015; Bouzarovski et al. 2014; Bouzarovski and Simcock 2017; Thomson et al. 2017; Scarpellini et al. 2019; Shahzad et al. 2022).

Across Europe, energy poverty has emerged as a growing policy concern, driven by a combination of rising energy prices, ageing building stock, and persistent income inequality. Recent estimates suggest that a substantial share of households experience difficulties in maintaining adequate indoor thermal comfort or meeting essential energy needs, with impacts extending beyond energy affordability to health, well-being, and social inclusion (European Commission et al. 2024; Thomson et al. 2017; 2017). In Ireland, these challenges are particularly pronounced due to a housing stock characterised by low energy efficiency, high dependence on fossil fuels for space heating, and comparatively slow rates of deep retrofit, increasing the exposure of households to energy cost shocks (ESRI et al. 2022).

Despite growing policy attention, the identification and measurement of energy poverty remain contested. Existing approaches rely heavily on single-dimensional indicators, such as fixed expenditure thresholds or income-based rules, which are often unable to capture the combined effects of affordability constraints and dwelling-related energy needs. Indicators such as the 10% rule or income-only measures may misclassify households that under-consume energy due to affordability pressures, or overlook those living in energy-inefficient dwellings with structurally high energy requirements (Hills 2011; Palma et al. 2024; Wojewódzka-Wiewiórska et al. 2024; Al Kez et al. 2024). As a result, the scale and nature of energy poverty can vary substantially depending on the indicator applied, raising concerns regarding robustness, comparability, and policy relevance.

In the Irish context, the measurement of energy poverty is further constrained by data availability and scale. While national surveys provide valuable insights into income and self-reported deprivation, they lack the spatial and technical resolution required to assess dwelling-specific energy needs. Conversely, the EPC database offers detailed information on building characteristics and modelled energy demand at the household level, but does not contain direct information on household income. This separation between economic and technical data has limited the ability to evaluate energy poverty consistently across indicators and at fine spatial scales, creating a methodological gap between policy monitoring and building-level intervention design.

Building on these conceptual and methodological debates in the energy poverty literature, the following section outlines the data sources and analytical framework used to operationalise and compare multiple energy poverty indicators at the household level in Dublin.

Methodology

The methodology consists of three main stages: (i) preparation and preprocessing of EPC data, (ii) Application of leading energy poverty indicators on a common analytical baseline, and (iii) household-level result generation and cross-indicator comparison for the Dublin residential stock.

Step 1: EPC dataset preparation and preprocessing

This study uses a cleaned and validated Irish EPC dataset for residential dwellings in Dublin as the primary technical evidence base. Each record represents an individual dwelling and includes dwelling descriptors, delivered energy by end use, heating fuel types, and energy performance ratings. The analysis is conducted at dwelling (household proxy) level.

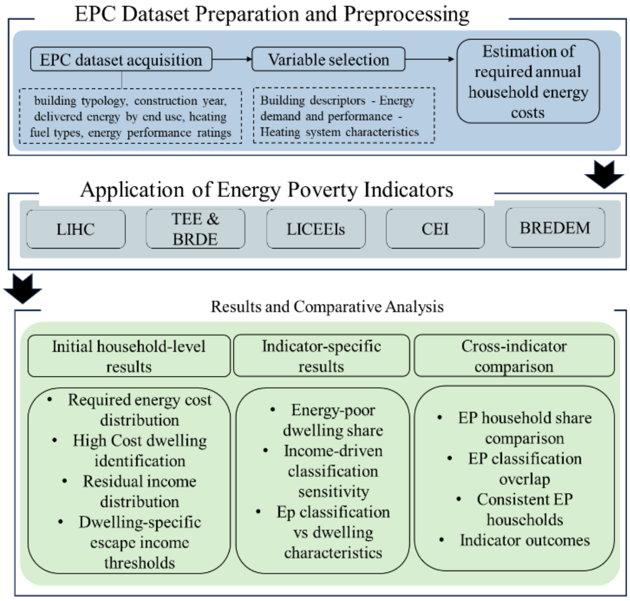

Figure 1: Methodological workflow for household-level energy poverty assessment using EPC data.

Variable selection and analytical dataset construction

To ensure methodological transparency and reproducibility, the full EPC dataset was reduced to a minimum set of variables required to apply the selected energy poverty indicators and to compute annual required energy costs. The retained variables were grouped into three categories: 1. Dwelling descriptors (unique dwelling identifier, dwelling archetype, Year of Construction, and BER Rating), 2. Delivered energy by end use (kWh/year) (space heating, water heating, lighting, fans and pumps, and other electricity uses where available), and Fuel type metadata (Main Space Heating Fuel and Main Water Heating Fuel).

These variables form the common input layer for all subsequent indicator implementations.

Estimation of required annual household energy Costs

Annual required household energy costs were estimated by converting delivered energy to cost using fuel-type-specific unit prices. Space-heating and water-heating costs were calculated by multiplying delivered energy (kWh/year) by the assigned unit price of the corresponding heating fuel. Electricity costs were computed by aggregating electricity-related end uses (lighting, pumps/fans, and recorded electricity consumption where available) and applying the electricity unit price. The total annual required energy cost for each dwelling was then calculated as:

$$C_i = C_i^{space} + C_i^{water} + C_i^{elec}$$

where C_i is the total required energy cost for dwelling i. This cost measure is treated as a required energy cost proxy derived from EPC data, enabling consistent comparison of structural energy burden across dwellings prior to introducing any income assumptions.

The resulting dataset provides a harmonised dwelling-level input layer comprising building descriptors, delivered energy by end use, fuel type information, and an estimated annual required energy cost, which together underpin the implementation of all subsequent energy poverty indicators.

Step 2: Application of energy poverty indicators

Following the preparation of a harmonised EPC-based analytical dataset and the estimation of required annual household energy costs, energy poverty was determined using a suite of leading indicators identified from the literature. To ensure comparability, all indicators were applied on a common technical baseline and evaluated consistently at dwelling (household proxy) level.

Given the absence of household income information in EPC data, income uncertainty was addressed through a scenario-based assumed-income framework, rather than income imputation or spatial proxies. This approach enables transparent sensitivity analysis and avoids introducing hidden bias into indicator application.

Income representation and poverty threshold

Household income was represented using a discrete set of assumed annual income levels spanning low to high income ranges. These income scenarios were applied uniformly across all dwellings, allowing assessment of how energy poverty classification responds to changes in income while holding building characteristics constant.

Low-income status was defined using the national at-risk-of-poverty threshold for Ireland, corresponding to 60% of the median equivalised disposable income. For the purposes of this study, the 2024 poverty line of €17,998 was adopted. This threshold was used consistently across all indicators incorporating income or residual income criteria.

Low income high costs (LIHC)

The LIHC indicator was implemented following the residual income formulation widely adopted in EU and UK methodological guidance. A dwelling was classified as energy poor if it simultaneously satisfied:

- High-Cost condition: Required annual energy cost exceeds the median energy cost of the Dublin sample (€2,129).
- Low Income condition: Residual household income after paying required energy costs falls below the poverty threshold (€17,998).

Formally, for dwelling i with assumed income Y and required energy cost C_i, energy poverty occurs when:

$$C_i > \text{Median}(C) \wedge (Y - C_i) < PL$$

where PL denotes the national poverty line.

In addition to binary classification, a dwelling-specific escape income was derived, defined as the minimum income required for a household to avoid LIHC classification given its energy cost.

Combined TEE & BRDE indicator

To reduce misclassification associated with single-threshold indicators, a combined TEE & BRDE indicator was applied. A dwelling was classified as energy poor if it simultaneously satisfied:

1. Energy expenditure exceeding 10% of household income (TEE),
2. Required energy cost above the median (BRDE),
3. Residual income after energy costs below the poverty threshold.

This combined formulation integrates affordability stress, relative energy burden, and income vulnerability within a single classification framework.

Low income combined with energy expenditure indicators (LICEEIs)

LICEEIs were implemented to capture households experiencing energy poverty due to the interaction of low income and energy-related constraints, including hidden energy poverty. The indicator combines low residual income status with either:

- high required energy costs, or
- unusually low energy consumption relative to dwelling characteristics (used as a proxy for under-heating).

This formulation enables identification of households whose energy poverty may not be fully captured by expenditure-based thresholds alone.

CEI (composite expenditure indicator)

CEI integrates multiple expenditure and income dimensions into a single composite score. Required energy costs and income measures were normalised and combined to produce a continuous vulnerability index, allowing households to be ranked by degree of energy poverty severity rather than classified using a binary threshold.

BREDEM-type model-based indicator

A BREDEM-type indicator was applied using EPC-derived delivered energy and building characteristics as proxies for required energy needs. By focusing on modelled energy demand rather than observed consumption, this indicator captures structurally driven energy needs and enables identification of hidden energy poverty associated with constrained energy use.

Step 3: results generation and comparative analysis

Following the application of the selected energy poverty indicators, results were generated and analysed at dwelling (household proxy) level for the residential building stock of Dublin. This step focuses on three complementary result layers: (i) initial household-level insights, (ii) indicator-specific outcomes, and (iii) cross-indicator comparison.

Initial household-level results for Dublin

The first stage of analysis examines the distribution of key energy poverty-related variables across the full sample of dwellings. This includes:

- distribution of required annual household energy costs,
- identification of high-cost dwellings,
- distribution of residual income under assumed income scenarios,
- derivation of dwelling-specific escape income thresholds.

These results provide an initial overview of structural energy burden and affordability stress within the Dublin housing stock. By analysing required energy costs prior to applying any indicator-specific thresholds, this stage isolates the role of building energy performance in shaping household vulnerability.

Descriptive statistics and distributions are used to highlight heterogeneity across dwellings and to identify segments of the housing stock exposed to disproportionately high energy costs, independent of income assumptions.

Indicator-specific results

In the second stage, results are analysed separately for each energy poverty indicator. For each indicator, the following outputs are produced:

- the number and proportion of dwellings classified as energy poor,
- sensitivity of classification to assumed household income levels,
- relationship between classification outcomes and dwelling characteristics (e.g. typology, construction period, energy rating).

For expenditure-based indicators (LIHC, TEE, TEE & BRDE), particular attention is given to the income levels at which households transition into or out of energy poverty. Dwelling-specific escape income thresholds are used to quantify how much income is required for households to avoid energy poverty conditional on building energy performance.

For composite and model-based indicators (LICEEIs, CEI, BREDEM-type), results are interpreted in terms of vulnerability intensity and structural energy need, enabling identification of households experiencing hidden or borderline energy poverty.

This indicator-specific analysis allows differences in sensitivity, strictness, and diagnostic capacity across indicators to be systematically assessed.

Cross-indicator comparison

The final stage of analysis compares results across all implemented indicators. This includes:

- comparison of the proportion of households identified as energy poor by each indicator,

- assessment of overlap and divergence in household classification,
- identification of households consistently classified as energy poor across multiple indicators,
- evaluation of how indicator choice influences conclusions regarding the scale and nature of energy poverty.

By applying all indicators to a common technical and income-scenario baseline, the analysis enables direct comparison of indicator behaviour and robustness. Differences in classification outcomes are interpreted in relation to each indicator's underlying conceptual focus, distinguishing between income-driven, expenditure-driven, and structure-driven vulnerability.

This comparative analysis forms the basis for identifying strengths and limitations of existing indicators and provides empirical grounding for the future development of a refined multidimensional energy poverty indicator tailored to the Irish context.

Result

Initial household-level outputs

The initial stage of the results focuses on household-level outputs derived directly from the cleaned and validated EPC dataset for Dublin. This stage aims to characterise the distribution of required energy costs, identify structurally high-cost dwellings, and assess affordability pressures prior to the application of income-based energy poverty indicators.

Distribution of required annual energy costs

Figure 2 illustrates the distribution of required annual household energy costs derived from the cleaned EPC dataset for Dublin. The distribution is markedly right-skewed, indicating substantial heterogeneity in energy cost requirements across the housing stock. While the majority of dwellings cluster at relatively low to moderate cost levels, a pronounced upper tail is observed, reflecting a subset of dwellings with exceptionally high required energy costs.

The dashed vertical line denotes the median energy cost threshold (€2,129), which serves as the structural high-cost benchmark within the LIHC framework. A considerable proportion of dwellings lie to the right of this threshold, demonstrating that high required energy costs are a widespread structural feature of the housing stock rather than a marginal phenomenon. This pattern indicates that energy affordability pressures in Dublin are not confined to a small number of extreme cases, but instead affect a substantial segment of dwellings prior to the application of income-based criteria.

Overall, Figure 3.1a provides direct empirical evidence that required energy costs are unevenly distributed and structurally driven, justifying the subsequent identification of high-cost dwellings and the application of income-sensitive energy poverty indicators in the following analysis.

To better visualise the upper tail of the cost distribution, the same data are shown on a logarithmic scale in Figure 3. This representation reveals a long and continuous upper tail, confirming that extremely high energy cost values are structurally embedded within the dataset rather than being isolated outliers. These high-cost dwellings are likely associated with unfavourable building characteristics, inefficient heating systems, or large floor areas, underscoring the importance of building-related factors in energy poverty analysis.

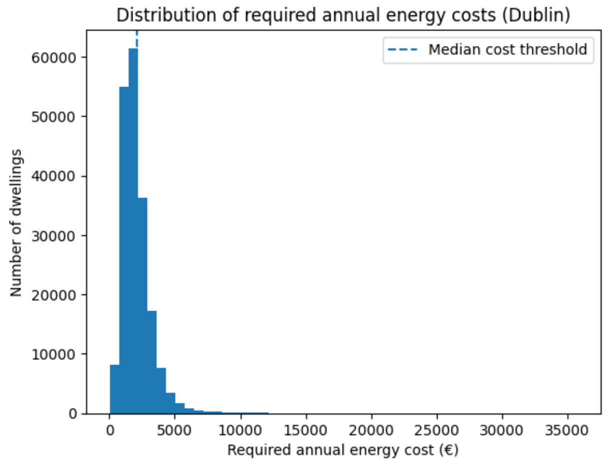

Figure 2: Distribution of required annual household energy costs (Dublin)

This pattern confirms that a subset of dwellings faces structurally elevated energy requirements spanning several orders of magnitude, reinforcing the role of building-related characteristics in shaping energy affordability pressures. The persistence of high-cost values beyond the median threshold further supports the identification of structurally high-cost dwellings prior to the application of income-based energy poverty indicators.

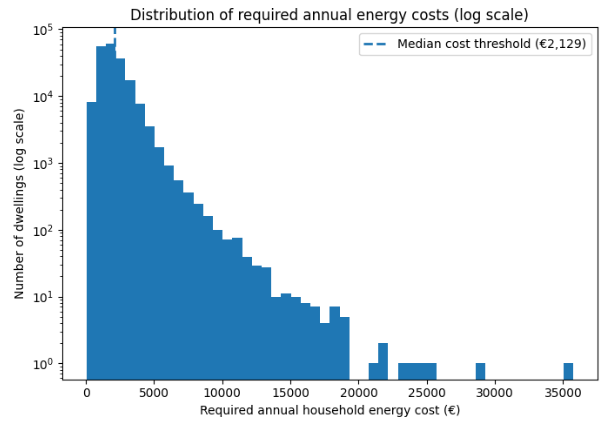

Figure 3: Distribution of required annual household energy costs (Dublin – log scale)

Identification of structurally high-cost dwellings

Using the median required annual energy cost (€2,129) as a structural threshold, dwellings were classified into high-cost and non–high-cost groups. Approximately 37% of dwellings in Dublin were identified as structurally high-cost, indicating that a substantial share of the housing stock faces elevated energy requirements independent of household income. This classification provides the basis for subsequent residual income and escape income analyses within the LIHC framework.

Escape income distribution for structurally high-cost dwellings

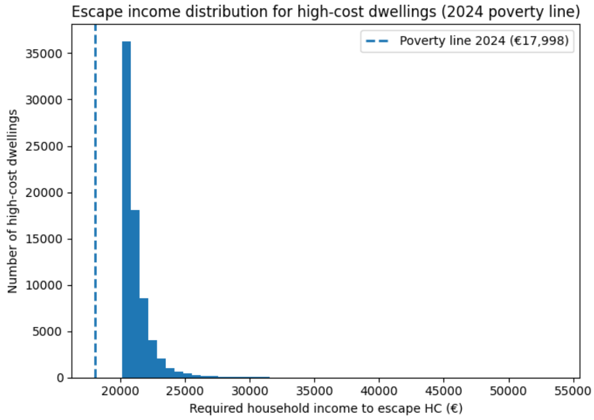

Figure 4. Distribution of escape income for high-cost dwellings

Indicator-specific results

The results reveal pronounced differences in both prevalence levels and income sensitivity across indicators. At very low assumed income levels (€10,000–€17,998), income-driven indicators such as LIHC, TEE & BRDE, and CEI identify approximately 37% of dwellings as energy poor, corresponding closely to the share of structurally high-cost dwellings. In contrast, indicators incorporating energy need and under-consumption dimensions exhibit substantially higher prevalence. LICEEI identifies approximately 52% of dwellings as energy poor, while the BREDEM-based proxy classifies up to 88% of dwellings as energy poor at the lowest income scenario. This divergence highlights the extent to which needs-based indicators capture vulnerability beyond income inadequacy alone.

As assumed household income increases, marked differences emerge in indicator sensitivity. For LIHC, TEE & BRDE, and CEI, energy poverty prevalence remains constant up to the poverty-line threshold (€17,998) and then declines sharply beyond €20,000, falling below 1% at €25,000. This stepwise reduction reflects the threshold-based nature of these indicators and their strong dependence on income adequacy.

In contrast, LICEEI and BREDEM exhibit a more gradual decline with rising income. Notably, at an assumed income of €20,000, LICEEI continues to classify 38% of dwellings as energy poor, while BREDEM identifies over 42%, indicating persistent vulnerability driven by high structural energy needs rather than low income alone. However, at higher income levels (€25,000 and above), convergence across indicators is observed, with prevalence dropping to negligible levels for all measures.

Overall, these results demonstrate that indicator choice substantially influences both the scale and interpretation of energy poverty. Income-driven indicators primarily identify affordability-driven vulnerability, while needs-based indicators reveal a broader set of households exposed to structurally driven energy hardship. This finding provides strong empirical justification for cross-indicator comparison and for the development of multidimensional approaches to energy poverty assessment.

Cross-indicator comparison

Figure 5 compares the sensitivity of energy poverty classification to assumed household income across all examined indicators. Clear and systematic differences are observed in both the level and persistence of energy poverty identified by each indicator, highlighting the strong influence of methodological choice on assessment outcomes.

At low assumed income levels (€10,000–€17,998), income-driven indicators (LIHC, TEE & BRDE, and CEI) converge at approximately 37%, closely matching the income-independent share of structurally high-cost dwellings. This indicates that, at low incomes, affordability constraints dominate classification outcomes, and energy poverty identification is primarily driven by the high-cost condition embedded within these indicators.

In contrast, indicators incorporating building energy needs and consumption constraints exhibit substantially higher prevalence. LICEEI identifies around 52% of dwellings as energy poor across low-income scenarios, while the BREDEM-based proxy reaches values as high as 88% at the lowest assumed income. This divergence demonstrates that needs-based indicators capture a broader set of vulnerable dwellings, including those facing high structural energy requirements that are not fully reflected in income-based measures.

As assumed income increases, sharp discontinuities emerge for income-sensitive indicators. For LIHC, TEE & BRDE, and CEI, energy poverty prevalence collapses rapidly beyond €20,000, approaching zero at €25,000 and above. This stepwise behaviour reflects the threshold-based structure of these indicators and underscores their strong dependence on income adequacy rather than persistent dwelling-level energy demand.

By contrast, LICEEI and BREDEM display a more gradual decline with increasing income. Notably, both indicators continue to identify a substantial share of households as energy poor at €20,000, indicating that elevated energy needs remain a significant source of vulnerability even when income approaches moderate levels. However, convergence across all indicators is observed at higher incomes, where prevalence becomes negligible, suggesting that income sufficiency eventually offsets structural energy cost pressures.

Overall, the cross-indicator comparison confirms that energy poverty is inherently multidimensional. Income-based indicators primarily identify affordability-driven vulnerability, while needs-based indicators reveal structurally driven energy hardship linked to building performance. These findings demonstrate that reliance on a single indicator risks mischaracterising both the scale and nature of energy poverty, providing strong empirical support for comparative and multidimensional assessment approaches.

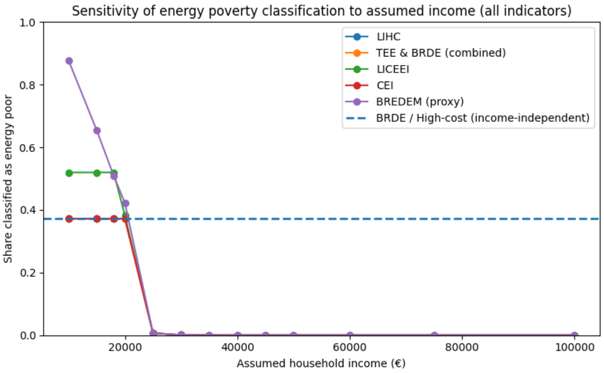

Figure 5: Sensitivity of EP share to income (all indicators)

Discussion and future directions

The results demonstrate that energy poverty in Dublin is strongly shaped by both household income and structurally driven energy costs associated with building performance. The initial household-level analysis shows a highly uneven distribution of required energy costs, with a substantial share of dwellings facing structurally high energy requirements. This structural heterogeneity directly translates into elevated escape income thresholds for many households, indicating that energy poverty cannot be explained by low income alone.

The indicator-specific and cross-indicator analyses further reveal that energy poverty prevalence and classification are highly sensitive to the choice of indicator. Income-based measures such as LIHC and TEE & BRDE primarily identify affordability-driven vulnerability and exhibit sharp threshold effects as income increases. In contrast, needs-based indicators, including LICEEI and the BREDEM-based proxy, capture a broader and more persistent form of vulnerability linked to building inefficiency and elevated energy demand. These findings confirm that reliance on a single indicator risks mischaracterising both the scale and nature of energy poverty.

From a policy perspective, the results highlight the need for integrated assessment frameworks in the Irish context. While income support measures may alleviate energy poverty for some households, the persistence of vulnerability among structurally high-cost dwellings underscores the importance of targeted building retrofit interventions. Future work in Ireland could benefit from the development of multidimensional energy poverty indicators that combine economic affordability, building energy performance, and aspects of household comfort and well-being, such as thermal adequacy and the ability to maintain healthy indoor conditions.

Several limitations should be acknowledged. The analysis relies on EPC-derived estimates of required energy costs rather than measured consumption, which may not fully capture behavioural effects such as under-heating or rebound. Household income was represented through assumed income scenarios, rather than observed microdata, which limits the ability to reflect actual income distributions. In addition, comfort-related dimensions were not explicitly quantified in the current framework.

Future research should therefore focus on integrating EPC data with household survey datasets and measured energy consumption where available, enabling more robust validation of energy poverty indicators. Expanding the framework to incorporate multidimensional well-being and comfort metrics would further enhance its relevance for policy design and evaluation, supporting more effective and equitable energy poverty interventions in Ireland.

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