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Operationalising the Lived Experience of Energy Vulnerability: Identifying Behavioural Trade-offs through Smart Meter Data

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Introduction & Background

Energy poverty affects nearly 20% of UK households, carrying substantial economic, health, and social costs. Yet, the metrics policymakers rely on most, such as the Low Income Low Energy Efficiency (LILEE) indicator, reduce a deeply lived experience to a static income threshold. They cannot capture what happens inside a household week to week: turning off the heating to afford food, letting a prepayment meter run out rather than accumulate debt, or enduring cold and damp conditions because no affordable alternative exists. These are behavioural trade-offs, and they are precisely what existing frameworks fail to see. Thus, there is a critical need to integrate high-resolution behavioural data with social frameworks to address this multifaceted challenge effectively.

Objectives & Approach

We operationalise a multi-stakeholder perspective on energy poverty by analysing longitudinal data from the Smart Energy Research Lab (SERL). Our methodological innovation is the Trade-off Proxy Variable (TPV): a composite behavioural indicator constructed from three flag signals directly observable in consumption records. The first, energy rationing, identifies households whose energy consumption significantly falls below a baseline adjusted for weather and property characteristics. This suggests that these households are intentionally restricting their energy use rather than simply being more efficient. The second, the inefficiency-consumption mismatch, flags households in poorly rated properties that display unusually low energy consumption. This indicates suppressed demand, as residents are unable to afford adequate heating in homes that are structurally expensive to heat. The third, extreme heating self-disconnection, captures instances of zero gas supply during freezing weather, highlighting households without heating during the coldest periods. A household is classified as acutely vulnerable when two or more signals co-occur. A competitive supervised machine learning framework, interpreted through SHapley Additive exPlanations (SHAP), is then applied to identify the structural drivers of these trade-offs.

Relevance to Digital Footprints

By moving away from static metrics, this research proposes that high-frequency energy logs serve as real-time digital proxies for financial vulnerability. AI modelling applied to these transactional records can uncover hidden patterns of self-disconnection and suppressed demand that demographic surveys routinely miss, offering a novel lens for behavioural data science with direct policy relevance.

Results

As a primary outcome, we present the engineered TPV architecture, a methodological framework designed to overcome the limitations of subjective survey data and static models. Critically, our technical evaluation of the SERL dataset, informed by existing literature, reveals that conventional economic indicators structurally underrepresent hidden vulnerability, particularly among 'house-rich but cash-poor' demographics who objectively engage in extreme rationing but underreport subjective hardship. This insight informs the behavioural design of the TPV: by grounding vulnerability classification in observable consumption patterns rather than self-reported income, we can highlight household profiles in acute distress that may be overlooked by conventional poverty classifications. At the conference, we will present the complete mathematical formulation of the three behavioural flags, our data-engineering strategy for addressing SERL sample biases, and the design of the machine learning pipeline. In the next phase of the project, we will leverage the extracted SHAP personas to quantify measurable gaps in 'know-what' and 'know-how.' This analysis will lay the empirical groundwork for targeted Marketplace Literacy interventions.

Conclusions & Implications

Tackling energy poverty requires shifting from top-down, income-based definitions to bottom-up, behaviourally grounded insights. The TPV framework, SHAP-driven persona methodology, and Marketplace Literacy pipeline together offer a scalable and replicable blueprint for policymakers and

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charities, enabling a transition from reactive welfare support to proactive identification of at-risk households before they reach a crisis point.

Keywords

deprivation, food vulnerability, interactive visualisation, area-level inequality, spatial