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The multiple consequences of energy poverty: A global meta-analysis

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HIGHLIGHTS

- We develop an integrated analytical framework linking energy poverty to social, economic, and environmental systems.
- A comprehensive meta-analysis is conducted based on 119 empirical studies worldwide.
- Greater energy poverty severity is associated with higher risks of adverse multidimensional consequences.
- The magnitude and structure of energy poverty impacts vary across income levels, regions, and development statuses.
- Methodological choices and measurement approaches significantly shape reported effect sizes in the literature.

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ABSTRACT

Energy poverty has attracted increasing academic attention, but its consequences are still dispersed across the social, economic, and environmental fields. This study provides a synthesis of the empirical evidence on 119 studies through a comprehensive meta-analysis. The results indicate that higher levels of energy poverty are consistently associated with greater risks of adverse outcomes, particularly in social and economic systems, while environmental consequences are less frequently examined and more heterogeneous. Meta-regression analysis further reveals background differences, estimating the extent of consequences across different income groups, regions, and development statuses, with stronger and more robust effects observed in low-income and developing economies. Methodological choices, measurement approaches, and temporal factors also influence reported effect sizes. These findings highlight the cumulative burden of energy poverty and the importance of contextual and methodological considerations when interpreting empirical results. Finally, we argue that integrated policy interventions, combining energy infrastructure development with targeted social welfare programs are essential to break the cycle of energy poverty and its cascading socioeconomic consequences.

1. Introduction

Energy poverty, defined as the lack of access to affordable, reliable and sustainable energy services, continues to be one of the most pressing global challenges to human development and climate resilience (Reddy et al., 2000; IEA, 2010). Despite the achievements made toward the SDG 7, critical gaps continue to persist (UN, 2023; IEA, 2024). As shown in Fig. 1(a), the global population without access to electricity increased in 2022 for the first time in nearly a decade. A regional breakdown in Fig. 1(b) also shows that progress has been uneven. Improvements in East Asia & Pacific and South Asia contrast with a persistent increase in the absolute number of people without electricity in Sub-Saharan Africa, where the challenge remains most concentrated. Even in developed economies, rising energy costs and supply chain disruptions have exacerbated "hidden energy poverty", forcing vulnerable households to make trade-offs between energy bills and basic necessities (EIA, 2022; BBC, 2024; Bouzarovski et al., 2025).

The severity of energy poverty varies greatly across countries, regions and population groups (UN, 2023). In low- and lower-middle-income countries, energy poverty is most evident in the persistent shortages of basic electricity and clean cooking fuels, with Sub-Saharan Africa and parts of South Asia remaining among the worst-affected regions globally (Che et al., 2021; González-Eguino, 2015). In this situation, a large number of households continue to rely on traditional biomass and face frequent power outages, which restrict basic living conditions and economic activities (Dato et al., 2025). In contrast, in middle- and high-income economies, energy poverty is increasingly a challenge

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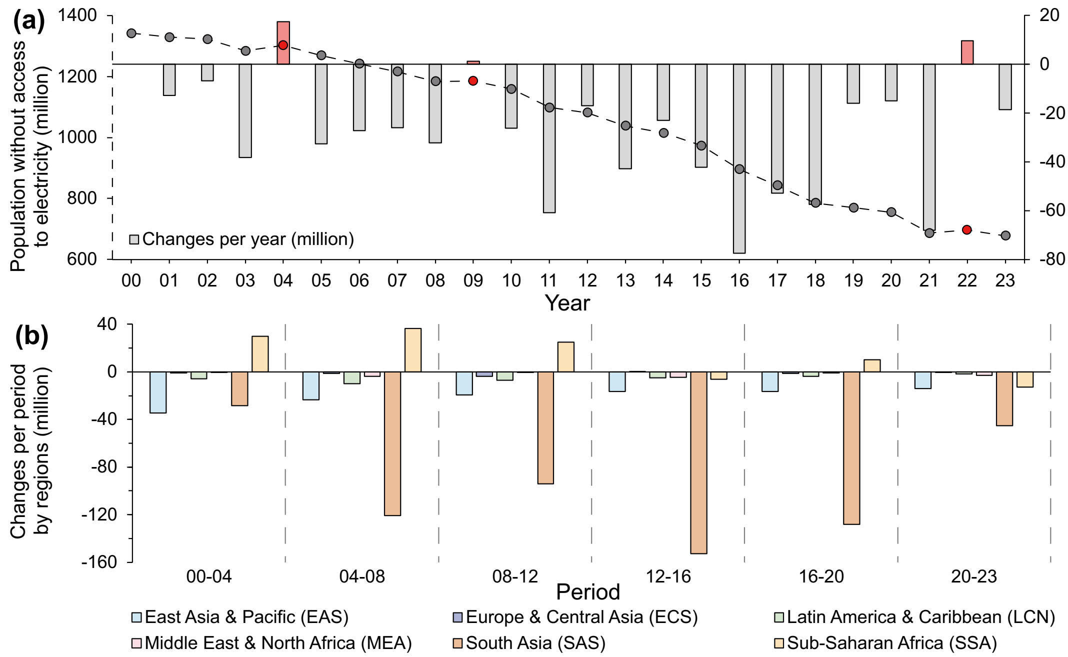

Fig. 1. Population without access to electricity and changes (2000–2023) (a) The line (left axis) shows the total population; the bars (right axis) show the change. Data source and classification standard: World Bank.

of affordability and adequacy, rather than absolute lack of access (Cong et al., 2022). Rising energy prices, inefficient housing stock, and climate-related extremes have exacerbated energy vulnerability for low-income households, older adults, and renters, even in countries where energy infrastructure coverage is nearly universal (Von Platten, 2022; Nawaz, 2021). Within the urban-rural divide, marginalized communities, informal settlements, and remote areas often face higher risks of energy poverty (Roberts et al., 2015; Mensah, 2022). These patterns suggest that energy poverty is a multidimensional condition, with its severity, indicators and affected groups varying across different levels of development and institutional contexts.

Moreover, the consequences of energy poverty extend far beyond mere energy deprivation, permeating social, economic, and environmental systems. Socially, prolonged exposure to indoor pollutants and extreme temperatures damages health (Churchill and Smyth, 2021; Karmaker et al., 2022; Sovacool, 2012), while educational opportunities are limited by poor lighting and digital exclusion, exacerbating intergenerational poverty (Banerjee et al., 2021; Oum, 2019; Belmin et al., 2022). Economically, households face spending traps as rising energy costs compete with other basic needs, while energy-constrained industrial activity and workforce health deficits put a strain on regional productivity (Guan et al., 2023; Sambodo and Novandra, 2019). Environmentally, reliance on traditional biomass fuels leads to the ecosystem degradation and household and environmental pollution (Casillas and Kammen, 2010; Nadimi and Tokimatsu, 2018), further hindering the transition to clean energy. In addition, these consequences are not isolated but play roles across the comprehensive system. For instance, energy poverty simultaneously deepens social and economic inequalities, creating a vicious cycle where health and educational disadvantages reduce productivity and income, which in turn perpetuates energy insecurity and widens the socio-economic divide (Nguyen and Nasir, 2021).

Existing evidence further suggests that the consequences of energy poverty are unevenly distributed across social groups and development statuses. Studies in developing economies tend to focus on losses in basic welfare, such as increased health risks, heavier time burdens, and limited human capital accumulation, while studies in developed economies more frequently report impacts on financial stress and social exclusion (Mei and Seo, 2024; Halkos and Gkampoura, 2021). Similarly, the economic consequences of energy poverty vary with income levels and industrial structure, ranging from survival-level productivity losses in low-income contexts to broader macroeconomic and labor market impacts in more developed economies (Ndubuisi et al., 2023; Scarpellini et al., 2019). The environmental consequences also vary across regions, with biomass dependence and local ecological degradation more prominent in low-income regions, while energy inefficiency and carbon-intensive coping strategies are more prominent in high-income regions (Dimnwobi et al., 2023; Casillas and Kammen, 2010). These cross-group differences suggest that similar levels of energy poverty can translate into different quality consequences depending on the context.

Despite the increasing amount of literature, several important gaps remain. First, the existing research is highly fragmented, focusing on single consequences, most commonly health or household well-being (Scarpellini et al., 2019; Sambodo and Novandra, 2019), without assessing the multiple social, economic, and environmental consequences of energy poverty within a unified analytical framework. Second, the empirical evidence is geographically and methodologically unbalanced, with some differences in measurement methods, model specifications, and control strategies, making cross-study comparisons difficult (Qurat-ul-Ann and Mirza, 2020). Third, while the majority of studies confirm that energy poverty negatively impacts social welfare, economic efficiency, and environmental quality, the extent and intensity of these effects vary across contexts. However, existing literature still lacks quantitative research on how factors such as income levels and geographic regions moderate these impacts.

Therefore, this study conducts a comprehensive meta-analysis of 119 empirical studies to assess the multiple consequences of energy poverty. We began by introducing an analytical framework that places the consequences of energy poverty within interconnected social, economic, and environmental systems, which helps clarify how different consequences are addressed in the existing literature. Although previous studies have provided descriptive summaries of the consequences of energy poverty, by combining bibliographic analysis with meta-regression method, we quantified the average effect size while specifically investigating heterogeneity across different income groups, regions, and development statuses. It further examines how sample characteristics and methodological factors modulate the intensity of these consequences in different systems. This allows us to identify how context and study design shape reported results, providing new insights into the differences in empirical findings across studies. We also found that the severity of energy poverty predicts more severe multidimensional consequences, particularly within social and economic systems, highlighting the urgent need for targeted interventions in ongoing energy transition strategies.

The remainder of this paper is organized as follows. Section 2 reviews the existing literature. Section 3 introduces the methodology of meta-analysis and details the data sources used in this study. Section 4 presents the results of the analysis, including meta-regression findings that explore the heterogeneity across studies. Section 5 proposes a discussion for understanding consequences of energy poverty in energy transition and outlines future research directions. Section 6 summarizes the key findings and offers policy implications.

2. Literature review

We synthesized the existing literature to show how energy poverty has multiple consequences across interconnected social, economic, and environmental systems. Based on the innovative analytical framework shown in Fig. 2, this review categorizes the literature according to the specific results within each system.

2.1. Social consequences

The social consequences of energy poverty are among the most widely studied in the literature, covering health, human capital, and socio-cultural outcomes. These impacts are both directly attributable to the lack of basic energy services and indirectly attributable to constrained household decision-making and social exclusion (Kaygusuz, 2011; González-Eguino, 2015).

Health impacts are the most direct and widely studied social consequences (Bollino and Botti, 2017; Banerjee et al., 2021). A large amount of evidence links energy poverty to adverse physical health outcomes, particularly through indoor air pollution from the use of traditional biomass fuels and unsafe energy practices (Churchill and Smyth, 2021; Zhang et al., 2021; Zhou et al., 2025). Such exposure increases the incidence of respiratory and cardiovascular diseases and exacerbates the vulnerability of children (Bentley et al., 2023). Inadequate heating and cooling further exacerbate the harm of extreme temperatures, leading to increased excess winter mortality and heat-related illnesses (Shi et al., 2025). Besides, the links between energy poverty and mental health and subjective well-being are increasingly evident (Charlier and Legendre, 2024; Nguyen-Phung and Le, 2024). Households with inadequate energy security often experience sustained stress, anxiety and psychological distress due to financial pressures and uncertainty about energy access (Li et al., 2022). As a result, energy poverty not only harms physical functioning, but also reduces life satisfaction and overall quality of life, exacerbating the disadvantage of vulnerable groups through both physical and psychosocial pathways.

Energy poverty also undermines human capital accumulation through its adverse impact on education (Rafi et al., 2021; Acheampong et al., 2024). Poor lighting, unreliable power supply, and limited access to digital technology reduce effective study time, limit access to educational resources, and hinder participation in increasingly important remote and hybrid learning formats (Oum, 2019). The impact of energy poverty on education is particularly pronounced in rural areas and low-income communities, where household poverty is often compounded by inadequate public infrastructure resources (Shon and Lee, 2025). Over time, persistent educational disadvantages undermine skill formation and labor market prospects, exacerbating cycles of low productivity and income vulnerability. By limiting opportunities for upward mobility, energy poverty contributes to the intergenerational transmission of disadvantage, linking short-term energy deprivation to long-term social and economic stagnation (Nsenkyire et al., 2023; Wang and Du, 2024).

Moreover, the cultural dimension reveals how social norms and behaviors influence and respond to energy access patterns (Liu et al.,

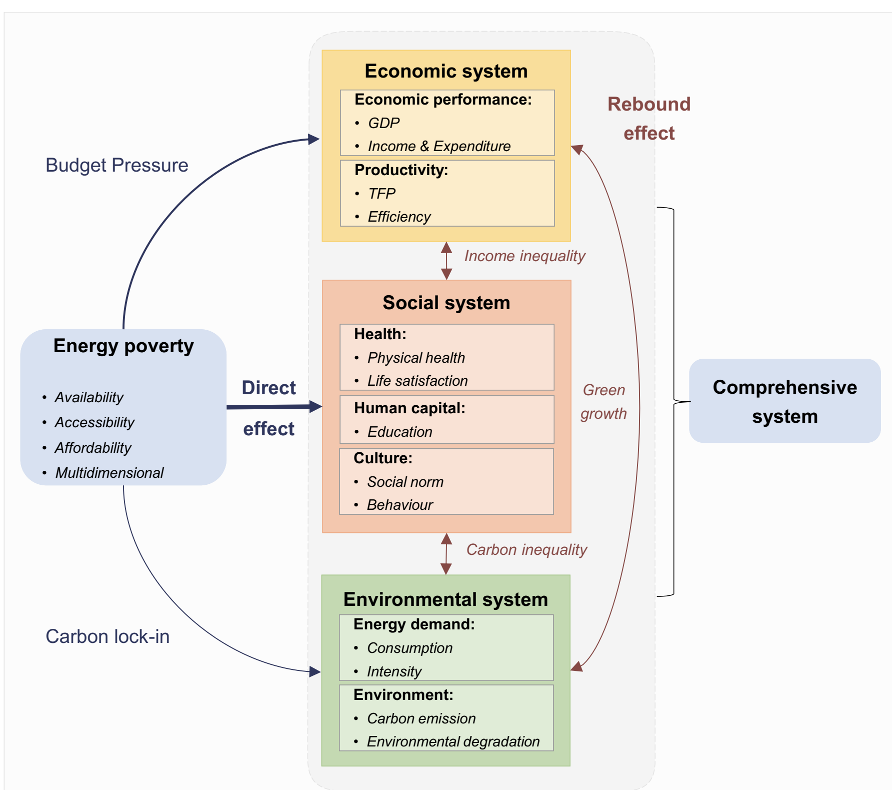

Fig. 2. Analytical framework for the consequences of energy poverty.

2024; Chang et al., 2024). When energy poverty becomes a long-term condition rather than a temporary shock, households often adapt by normalizing discomfort, restricting energy-intensive activities, and adjusting social expectations of thermal comfort, cleanliness, and leisure (Cong et al., 2022). Such adaptations are not neutral coping mechanisms; rather, they reflect constrained choices that can mask deprivation while entrenching vulnerability. These behavioral responses often translate into reduced social participation and restricted mobility (DellaValle, 2019). As a result, over time, energy poverty can weaken social networks and erode informal support systems, particularly for women, older people and other vulnerable groups who spend more time in the home. Recent evidence further suggests that energy deprivation interacts with deeply entrenched cultural norms to influence fertility intentions, gender roles and intra-household power dynamics (Zhang and Petrova, 2026), thereby exacerbating existing social inequalities rather than simply reflecting them.

2.2. Economic consequences

The economic consequences of energy poverty manifest through household-level budget constraints, productivity losses, and aggregate economic performance, reflecting both microeconomic and macroeconomic mechanisms.

At the household level, energy poverty can create budgetary pressures through excessive energy expenditure relative to income (Khandker et al., 2012; Bardazzi et al., 2021). When energy costs consume a large portion of household's budget, the household is forced to reallocate resources from other essential goods, such as health care and housing maintenance (Pachauri et al., 2004). Expenditure trade-offs, often described as the "energy burden" effect, are common in both developing and developed economies (Brown et al., 2020). This problem is often exacerbated by volatile energy prices, inefficient housing stock, and limited access to energy-efficient technologies (Guan et al., 2023; Li et al., 2021; Burlinson et al., 2018). As a result, energy-poor households face greater financial stress and reduced financial resilience, which in turn limits their ability to smooth consumption or invest in productivity-enhancing activities (Dogan et al., 2021; Khandker et al., 2012). Energy poverty is therefore seen as a key mechanism through which income constraints are amplified into broader economic vulnerability.

Beyond household finances, energy poverty affects productivity in a variety of ways and at different scales (Ndubuisi et al., 2023; Nguyen and Su, 2021). At the micro level, lack of energy access constrains household-based enterprises, limits the use of modern appliances and information technology, and reduces labor productivity due to poor health and time lost to fuel collection or coping strategies (Avordeh et al., 2024). These constraints are particularly common in rural and informal economies, where small-scale production and self-employment are heavily reliant on reliable energy services (Ruiz-Rivas et al., 2023). At the macro level, widespread energy deprivation undermines industrial output and reduces total factor productivity, especially in energy-intensive industries (Nguyen and Su, 2021). Furthermore, some studies have linked high levels of energy poverty to lower GDP growth (Garba and Bellingham, 2021), suggesting that energy poverty can act as an amplifier of economic development conditions, rather than simply reflecting existing gaps.

2.3. Environmental consequences

The environmental consequences of energy poverty have received relatively little attention, but are increasingly recognized as critical, particularly in the context of climate change and energy transition (Churchill et al., 2022; Chakravarty and Tavoni, 2013; Casillas and Kammen, 2010).

Energy poverty also affects energy demand patterns, further leading to different levels of consumption and energy intensity in different contexts (Yasmeen et al., 2023; Boemi and Papadopoulos, 2019). In low-income contexts, reliance on traditional biomass and inefficient fuels leads to high energy intensity per unit of useful service, reflecting technical inefficiency rather than over-consumption. In contrast, in high-income contexts, energy-poor households often under-consume basic energy services such as heating, cooling, and lighting (Cong et al., 2022; Boemi and Papadopoulos, 2019). This suppressed demand may be misinterpreted as efficiency, when in fact it reflects unmet needs and reduced living standards. Therefore, low energy consumption should not be simply equated with sustainability, but rather a distinction needs to be made between efficiency gains and deprivation due to under-consumption.

From an environmental perspective, energy poverty contributes to local environmental degradation and climate challenges in a number of ways (Villanthenkodath et al., 2024; Messie Pondie and Engwali, 2024; Zhao et al., 2024). Reliance on solid fuels accelerates deforestation and land degradation, while inefficient combustion generates high levels of particulate matter and black carbon emissions (Zhao et al., 2021). These local environmental impacts have significant public health implications, exacerbate climate change, and increase the social costs of energy poverty (Jessel et al., 2019; Zaman et al., 2016). At the same time, energy-poor households often lack the financial, informational and institutional capacity to adopt clean and low-carbon technologies, delaying the adoption of renewable energy and energy-saving solutions.

Importantly, the potential carbon lock-in effects associated with energy poverty have also been identified (Zhao et al., 2023). Limited access to modern energy infrastructure can lock households and communities into carbon-intensive pathways, while poorly designed energy transition policies, such as uniform energy price increases or subsidy removal without compensatory measures, can inadvertently exacerbate energy poverty (Gregory and Sovacool, 2019; Primc and Slabe-Erker, 2020). This highlights the key tension between decarbonization and equity goals.

2.4. Comprehensive consequences

Energy poverty does not only affect one area of life. Its consequences spread through different fields and create cycles where problems exacerbate each other. This means that a difficulty in one system often leads to problems in another (Scarpellini et al., 2019).

On one hand, social systems are both the primary field of consequences and the key channel through which impacts are transmitted to other systems. Energy poverty directly undermines health, educational attainment, and well-being, exacerbating social inequalities. Importantly, these social deficits trigger severe economic and environmental repercussions. Income inequality both causes and is exacerbated by energy poverty, creating a cumulative disadvantage (Igawa and Managi, 2022; Dong et al., 2022). Impaired health and education reduce labor productivity and human capital, constraining economic growth (Banerjee et al., 2021). At the same time, coping strategies adopted by energy-poor households, such as relying on solid fuels for cooking and heating, directly exacerbate indoor and local air pollution, creating a clear pathway from social hardship to environmental degradation (Xu and Chen, 2019). The poorest populations, who have contributed the least to historical and per capita emissions, disproportionately bear the health and economic burdens of pollution and climate change impacts, further entrenching their social disadvantage.

On the other hand, the relationship between economic and environmental systems is deeply influenced by the consequences of energy poverty. Economically, energy poverty constrains productivity, suppresses income growth, and limits investment in clean technologies. These constraints in turn force reliance on cheaper, more polluting energy sources, directly worsening local environments through increased emissions and resource depletion (Zhao et al., 2022). It creates a vicious cycle where environmental degradation further undermines economic resilience and exacerbates energy insecurity. A key feature of it is the rebound effect in energy poverty alleviation.

When efficiency improvements or subsidies make energy services more affordable, increased consumption may partially offset environmental gains. If poorly managed, it can even raise total energy expenditures for vulnerable households (Kong et al., 2023). Thus, energy poverty not only stems from the tension between economic development needs and environmental sustainability objectives but also actively exacerbates this tension.

3. Methods and materials

3.1. Literature search and screening

To ensure comprehensive identification of relevant studies, we conducted a literature review following PRISMA guidelines (Moher et al., 2010). The search covers publications up to December 2024 and is implemented in three major academic databases: Web of Science, Scopus, and Google Scholar, which together provide broad coverage of peer-reviewed research in the fields of energy, economics, and social sciences.

Our search strategy focuses on keyword matching based on titles to ensure conceptual relevance. Specifically, we used a combination of "Energy poverty", "Energy poor", "Fuel poverty", and "Fuel poor," which are widely used in the literature to describe aspects of energy deprivation at the household level. Limiting the research to titles helps to minimize low relevance results and ensure that energy poverty is a core concern of the selected study, rather than a marginal topic of analysis.

Studies are included based on four criteria: (i) Publication type: Peer-reviewed journal articles; (ii) Language: Studies published in English; (iii) Publication date: Studies published after 2000 to ensure relevance to contemporary energy poverty issues; (iv) Methodology: Studies employing quantitative methods.

The initial search identified 1795 potentially relevant articles. We then screened titles and abstracts, followed by full-text assessment, to exclude conceptual papers, qualitative studies, and articles that did not explicitly provide empirical estimates of the consequences of energy poverty. After multi-stage screening, 119 studies reporting usable empirical results were retained for meta-analysis.

3.2. Data extraction and coding scheme

Following the analytical framework, we categorized the reported consequences of energy poverty into three systems: social, economic, and environmental. For each study, we extracted detailed information about outcome variables, including the specific indicators used to capture the outcome, the estimated coefficients linking energy poverty to these outcomes, and all available measures of statistical uncertainty, such as standard errors, confidence intervals, and sample sizes. In addition, we recorded the full set of covariates included in the original empirical models to facilitate interpretation and comparison across studies.

To ensure comparability across studies, all reported estimates were standardized following established practices in meta-analysis. Specifically, each coefficient was normalized using its associated standard error and sample size, converting heterogeneous empirical measures into a common measure of effect size. This approach preserves the direction and relative magnitude of estimated relationships while allowing meaningful aggregation across different model specifications, datasets, and outcome variables. The resulting standardized effect sizes provide a consistent basis for synthesizing evidence on the multidimensional consequences of energy poverty.

To facilitate the meta-regression of the results, we developed a coding scheme to classify the key variables and the results of interest. The dependent variable is the consequences of energy poverty, i.e., the elasticity of energy poverty in the original studies. The independent variables are the characteristics of the original studies that affect the results, which are divided into sample characteristics and control variables.

First, we examined the distribution of countries based on the previous studies, focusing on three core sample characteristics.

1. The "*Development status*": Countries are divided into either "Developing" or "Developed". We treated "Developed" as the baseline.
2. The "*Income groups*": Countries are divided into three income group: "Low-income countries and Lower-middle-income countries (LICs & LMICs)", "Upper-middle-income countries (UMICs)", and "High-income countries (HICs)". We treated "HICs" as the baseline.
3. The "*Regional group*": Countries are divided into four major regional groups: "East Asia & Pacific (EAS)", "South Asia (SAS)", "Sub-Saharan Africa (SSA)" and "Others". We treated "Others" as the baseline.

The reasons for this choice are as follows: Development status captures fundamental socioeconomic and institutional differences at the country level. Income group further distinguishes the gradient of economic resources, particularly within developing economies. Regional group accounts for spatial heterogeneity that may not be fully explained by the first two dimensions. Together, these three sample characteristics form a hierarchical analytical framework that progresses from macro-structural context, through economic resource levels, to geographic and contextual heterogeneity.

Second, we introduced the following six control variables to account for variations in measurement methods, model settings and data characteristics in the original studies. These variables enable us to distinguish between substantive heterogeneity in the consequences of energy poverty and differences in study design.

1. The "*EP* (*Mul*)": A binary variable that identifies studies measuring energy poverty using a multidimensional approach. The multidimensional indicators often include factors such as availability, accessibility, and affordability, offering a more comprehensive assessment than unidimensional indicators (Additional clarification is provided in Fig. A.1).
2. The "*EP* (*Score*)": A binary variable indicating that energy poverty is measured as a continuous variable. Continuous measures allow for nuanced analysis, whereas discrete classifications may simplify empirical relationships.
3. The "*Method* (*Identify*)": A categorical variable representing the estimation method employed in the original studies, including Ordinary Least Squares (OLS), Fixed Effect (FE), Random Effect (RE), Instrumental Variables (IV), Gaussian Mixture Model (GMM), and other methods. This classification ensures that methodological diversity is controlled for in meta-analytical comparisons.
4. The "*Method* (*Control*)": The number of control variables included in each primary study. This variable represents the complexity of the model and the extent to which confounding factors are addressed.
5. The "*Time* (*2015*)": A binary variable distinguishing studies that incorporate post-2015 data. This controls for the adoption of the Sustainable Development Goals (SDGs), which may have influenced energy poverty measurement and policy priorities.
6. The "*Time* (*Publish*)": The year of publication, included to account for temporal trends in research focus and methodological advancements.

The specific descriptions of all variables are shown in Table 1. And the summary statistics of control variables are shown in Table 2.

3.3. Meta-regression modeling strategy

To quantify the heterogeneity of the energy poverty reporting consequences of different sample characteristics, we constructed the following

Table 1
Description of variables in meta-regression.

Variables	Symbols	Definitions
Dependent variable	γ_i	The reported estimated coefficient of β in ith study
Sample characteristic	Development status	The group of development status to which the study countries belongs (Developing, Developed)
	Income group	The income group to which study belongs (LICs & LMICs, UMICs, and HICs)
	Regional group	The regional group to which study belongs (EAS, SAS, SSA, and Others)
Control variable	EP (Mul)	= 1 if the energy poverty measured with multidimensional approach
	EP (Score)	= 1 if the energy poverty is a continuous variable
	Method (Identify)	The estimation method to which study uses; 1 = OLS; 2 = RE/FE; 3 = Endogeneity methods such as IV/GMM; 4 = Others
	Method (Control)	Number of control variables
	Time (2015)	Does it include data after 2015
	Time (Publish)	Year of publication

Table 2
Summary statistics of control variables.

Variable	No. of obs.	Mean	SD	Min	Max
EP (Multi)	941	0.3847	0.4868	0	1
EP (Score)	941	0.5887	0.4923	0	1
Method (Identify)	941	2.5813	1.1095	1	4
Method (Control)	941	6.7109	3.4350	0	17
Time (2015)	941	0.8417	0.3653	0	1
Time (Publish)	941	2022.3	1.4921	2019	2024

meta-regression model, with reference to Stanley and Jarrell (2005):

$$\gamma_i = \alpha + \sum_{k=1}^{M} \beta_k Z_{1ij_k} + \sum_{m=1}^{6} \beta_m Z_{2im} + \varepsilon_i \tag{1}$$

where γ_i is the estimated consequence of energy poverty, i.e., the elasticity of energy poverty in previous studies. To enable meaningful comparison across studies that use differently polarized indicators, we use the absolute value of standardized coefficients in our baseline meta-regression. This approach allows us to focus on the strength of the association between energy poverty and its consequences, while avoiding artificial sign reversals resulting from measurement choices. In addition, Z is a set of heterogeneous factors that lead to differences in the empirical results of the original studies, where Z_1 is the sample characteristic, which includes three distinct dimensions: development status, income group, and regional group, j is the category of sample characteristics, k is the group included in the category; Z_2 is the control variable.

In this regression model, the explanatory variables are composed of two parts. The first captures the sample characteristics, enabling us to assess how the severity of energy poverty consequences varies across different socioeconomic and geographic contexts. The second category includes study-level control variables that reflect differences in measures of energy poverty, empirical methods, and scope of time. To avoid multicollinearity and to distinguish the unique explanatory role of each dimension, the three sample characteristics in Z_1 are not entered simultaneously into a single model. Instead, they are introduced in a stepwise manner in separate models. First, we assess the baseline difference using development status. Then, within the developing country subset, where most observations are concentrated, we further examine the gradient effect of income group. Finally, regional group is controlled for to account for geographic and contextual heterogeneity.

In addition, in order to address the methodological challenges posed by between-study heterogeneity and potential heteroskedasticity in meta-regression, we employed a multi-estimator framework. Our primary analysis is based on Restricted Maximum Likelihood (REML) estimation, which is widely recommended for random-effects meta-regression due to its ability to provide efficient and less biased estimates of between-study variance (Khanna et al., 2021; van der Linden and Goldberg, 2020). We further complemented this with Empirical Bayes (EB) estimation, which stabilizes effect estimates through hierarchical shrinkage, particularly for studies with higher sampling variability. In direct response to concerns regarding heteroskedasticity, we conducted robustness checks using Ordinary Least Squares (OLS) and Weighted Least Squares (WLS) specifications, in which robust standard errors were applied to ensure reliable inference under potential variance instability. While REML and EB appropriately model between-study heterogeneity, the OLS and WLS analyses with robust standard errors provide an additional layer of validation against residual heteroskedasticity.

All estimators reported in the main results are derived from REML estimation. The consistency of findings across REML, EB, OLS, and WLS models confirms that our conclusions are not sensitive to the choice of estimator or to heteroskedasticity in the meta-regression residuals. Based on these models, our analysis is conducted in two steps. First, we aggregate all standardized effect sizes to determine the role of sample characteristics in various outcomes of energy poverty across domains. Second, we perform subgroup regression by domain to examine whether these sample characteristics act consistently or exhibit system-specific patterns.

4. Results

4.1. Bibliographic results

4.1.1. Publication trends

Fig. 3 shows the evolution of the degree of attention paid to energy poverty by the academic community and the public.

Fig. 3(a) reveals a clear acceleration in academic publications on energy poverty. Before 2010, the literature remained scarce and sporadic, with only a few studies published each year. The first notable increase occurred after 2010, coinciding with a growing international awareness of energy access as a key development and welfare challenge. A turning point was marked by two key policy milestones: the adoption of the 2030 Agenda for Sustainable Development in September 2015 and the Paris Agreement in December of the same year. Since 2015, the number of publications has steadily increased, indicating that energy poverty has become an important component of global sustainable development and climate policy.

The second, more notable, increase occurred after 2019. The outbreak of COVID-19, and the Russia-Ukraine conflict in 2022, appear to have greatly intensified academic attention. These shocks exposed the vulnerability of households to income disruption, energy price volatility, and supply insecurity, thereby expanding research focus from measurement issues to multidimensional consequences. This shift is evident in the literature. While early research primarily focused on measuring energy poverty and analyzing its patterns, studies examining the consequences and influencing factors of energy poverty have rapidly expanded in recent years (González-Eguino, 2015). By 2024, consequence-oriented studies increasingly dominate the literature, highlighting the growing concern about the social, economic, and environmental impacts of energy poverty.

Fig. 3(b) draws attention to Google search trends, complementing the bibliometric evidence. Searches related to "Energy poverty" and "Energy poor" remained relatively stable until 2019, but have since increased sharply, peaking around 2021–2022. This pattern is closely associated with major global disruptions, particularly energy price shocks following emergencies and geopolitical conflicts. In contrast, search interest in "Fuel poverty" and "Fuel poor" showed an earlier but more moderate

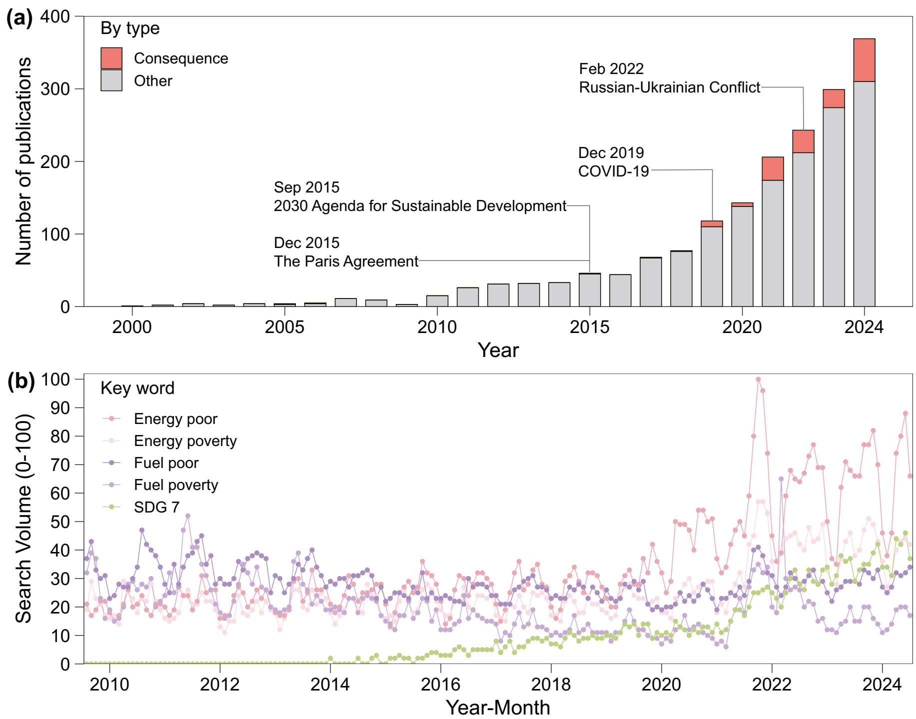

Fig. 3. Academic and publication attention to energy poverty. (a): Publication trends (2000–2024). (b): Google search interest (2010–2024).

trend, reflecting their long-standing use in specific regional contexts, particularly in developed economies. Notably, interest in “SDG 7” remained negligible until 2015, but has since risen steadily, indicating the gradual permeation of the sustainable development agenda into public discourse.

In summary, Fig. 3 shows a strong convergence between academic research and public attention. Energy poverty has evolved from a specialized research topic to one that is studied in the context of different crises. The rapid expansion of consequence-focused research suggests that the literature has moved from identifying and measuring energy poverty to understanding its various impacts. This trend provides clear rationale for synthesizing the existing evidence on the various systemic consequences of energy poverty.

4.1.2. Distribution of observations

To identify the core focus of existing research, it is necessary to comprehensively characterize high-frequency keywords in literature titles. Therefore, we conducted a word cloud analysis of the titles from 119 selected studies, with the results shown in Fig. 4.

The keywords “Health”, “Well-being”, and “Multidimensional” are the most prominent in the word cloud results, indicating that the existing literature has gone beyond the traditional view of energy poverty as a single economic constraint. Instead, it is increasingly understood as a form of multidimensional poverty with broad social impacts. Among them, health and subjective well-being have become the most core research results, reflecting how energy poverty profoundly affects the physical and mental health and quality of life of families through

Fig. 4. Word cloud based on the titles of selected literature.

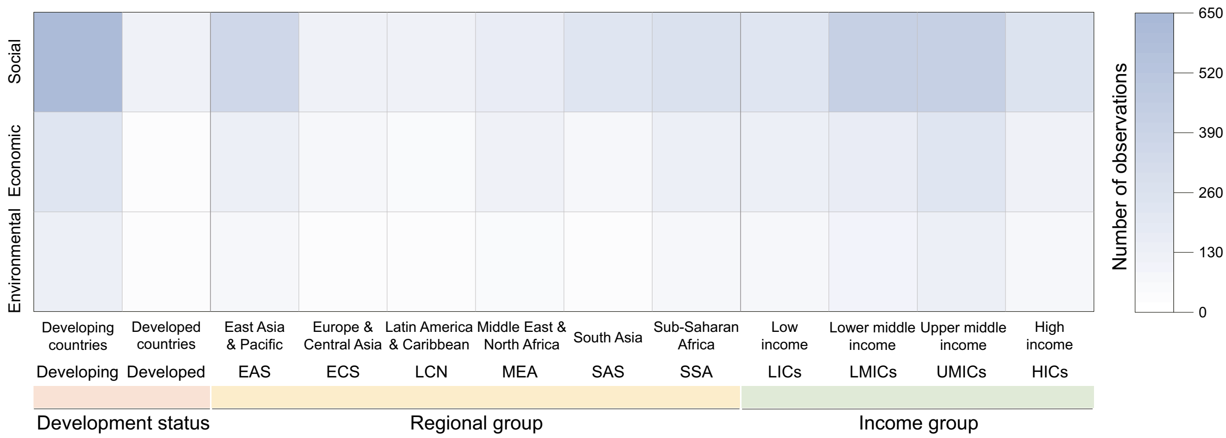

Fig. 5. Distributions of sample characteristics.

mechanisms such as indoor environmental quality, heating and cooling conditions, and access to clean energy. At the same time, the frequent appearance of keywords such as “Income”, “Education”, “Mental”, “Productivity”, and “Inequality” further indicates that the research has gradually expanded to multiple dimensions such as human capital accumulation, mental health, labor productivity, and social inequality, highlighting the long-term and structural impacts of energy poverty.

In terms of research objects and spatial distribution, keywords such as “China”, “Africa”, “Sub-Saharan”, and “Rural” occupy important positions. This shows that the existing empirical evidence mainly focuses on developing countries and rural areas, with special attention to household phenomena in China and Sub-Saharan African countries. This feature reflects the serious reality of energy poverty in these regions and indicates that the current conclusions may show a certain degree of context dependence. In addition, keywords related to demographic characteristics, such as “Women”, “Children”, “Older”, and “Household”, often appear, which indicates that research is increasingly focusing on the heterogeneous impacts of energy poverty within households and its distributional impact on vulnerable groups.

In summary, this word cloud clearly reveals the key features of energy poverty consequences research, including its focus on health and well-being, its multidimensional expansion, and its focus on developing regions. It also indirectly highlights the need to integrate and quantitatively compare the effects of different outcomes, which is also the core motivation for conducting this meta-analysis.

Fig. 5 presents the distribution of observations across three sample characteristics in our meta-analysis.

On one hand, most current research remains concentrated along geographic and economic boundaries. Over two-thirds of observations originate from developing economies, particularly in Sub-Saharan Africa and South Asia where energy access deficits are most severe. Upper-middle-income countries represent the most studied income group, reflecting a research focus on economies in transitional development phases where energy poverty often coincides with rapid urbanization and rising inequality. On the other hand, the distribution reveals distinct field imbalances. Social consequences, including health, education, and well-being outcomes, dominate the evidence base across nearly all regional and income groups. Economic consequences, while also constituting a sizable proportion, exhibit uneven coverage, peaking in upper-middle-income countries and certain developing countries. Most notably, environmental consequences are severely underrepresented, with observations accounting for only a small proportion even in regions where energy poverty-related emissions or indoor air pollution are pressing concerns.

To assess the empirical robustness and comparability of the meta-analytic sample, we further examined the distribution of all control variables in terms of measures of energy poverty, empirical methods, and scope of time (Fig. 6). These characteristics provide important evidence for interpreting the estimated consequences of energy poverty and help to identify potential sources of heterogeneity across studies.

The literature exhibits great diversity in the measures of energy poverty. Multidimensional definitions coexist with unidimensional approaches, the latter being more common, reflecting the continued reliance on unidimensional measures such as expenditure-based or access-based metrics. Similarly, score-based measures are more commonly used than dummy variables, indicating a growing tendency to capture the intensity of energy poverty rather than binary classification. This heterogeneity in measurement suggests the importance of considering the type of indicator in meta-regression analysis, as different constructions may introduce methodological bias in the estimation results.

Regarding empirical methods, a large proportion of studies in the sample employ methods to address endogeneity (such as IV or GMM) in addition to traditional OLS and panel fixed or random effects models. This distribution indicates an increasing diversity of research methodologies in the field, but also implies that the credibility and level of reported effects vary. The number of control variables included in empirical models is generally moderate, with most studies including between 4 and 11 covariates. This suggests a balance between model parsimony and control for confounding factors, although a small number of studies employ highly saturated specifications.

Finally, the scope of time requires explicit consideration in two key dimensions. First, the temporal distribution of the sample shows a clear bias toward the post-2015 period, which coincides with the adoption of the SDGs. Second, the distribution of publication years reveals a sharp increase in research output after 2020, reflecting heightened academic and policy attention in the wake of volatile energy prices and the global energy transition. This temporal concentration reinforces the relevance of recent policy shocks in shaping the empirical evidence base, while also motivating rigorous controls for publication year and post-2015 effects in meta-analysis.

4.2. Empirical results

We conducted meta-regression analysis to analyze the multidimensional consequences of energy poverty. This approach allows for the quantification of effect sizes while controlling for study-level heterogeneity, with the REML estimation accounting for both sampling error

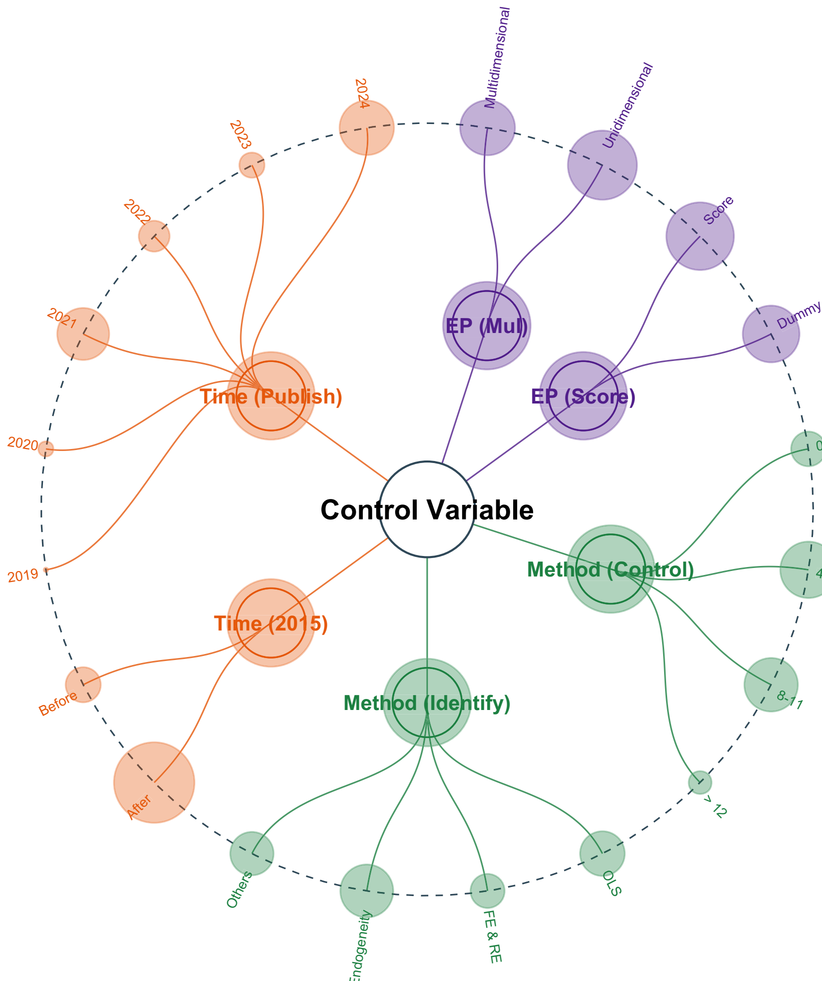

Fig. 6. Distributions of control variables. Variables are color-coded by category: measures of energy poverty, empirical methods, and scope of time.

and between-study variance. Our analysis examines different consequences at different stages of development, focusing on social, economic and environmental systems. The robustness test results of the EB, OLS, and WLS models are shown in Appendix B.

4.2.1. Development status

As shown in Table 3, the estimated results from the REML-based meta-regressions exhibit heterogeneity when countries are grouped by development status. Compared to developed economies (the baseline), studies focusing on developing countries report much larger overall consequences of energy poverty, with positive and statistically significant impacts on the entire social and economic system. Notably, the economic consequences are more severe, suggesting that energy poverty in developing contexts more directly constrains income-generating activities, labor productivity, and household economic resilience. In contrast, the environmental consequences exhibit a statistically insignificant negative coefficient, suggesting that the environmental outcomes associated with energy poverty are more heterogeneous and less consistent in studies of developing countries. Overall, the findings on development status support the conclusion that the consequences of energy poverty are more severe in developing countries, while the environmental impacts remain relatively less clear in the existing empirical literature.

Among the control variables, several consistent patterns are further identified. In terms of measurement choices, the use of energy poverty scores is associated with larger estimated impacts on the overall and social systems, while multidimensional indices tend to show smaller or weaker consequences. This pattern suggests that continuous and intensity-based measures may better reflect the severity of energy poverty and its social impacts in developing countries.

Methodological complexity positively correlates with reported effect size across overall and social consequences, suggesting that studies that rigorously address econometric issues tend to find stronger impacts. In contrast, more control variables in the original studies are associated with smaller estimated effects in overall and social consequences, indicating potential overestimation in more simplified specifications. Finally, significantly negative coefficients for the post-2015 period and publication year indicate a declining trend in reported effect sizes over time, reflecting improvements in energy access, policy interventions aligned with SDGs, or more conservative estimates in publications.

4.2.2. Income group

Table 4 reports the results of the REML-based meta-regression with HICs as the baseline. These results show that there is also heterogeneity in the effect size across income groups, especially when distinguishing between social, economic, and environmental consequences. We considered LICs and LMICs together because the number of observations for LICs is relatively small, so we combined them with LMICs, which are closest in income level.

Table 3
Meta-regression results by development status.

	Overall	Social	Economic	Environmental
Developing	0.0907**	0.0881**	0.1706**	−0.1518
	(2.54)	(2.08)	(2.06)	(−0.49)
EP (*Multi*)	−0.0387*	−0.0311	−0.1355***	−0.1116
	(−1.72)	(−1.14)	(−3.22)	(−1.61)
EP (*Score*)	0.0619**	0.0757***	0.0092	0.1275
	(2.53)	(2.60)	(0.16)	(0.46)
Method (*Identify*)	0.0329***	0.0424***	0.0108	0.0080
	(3.46)	(3.67)	(0.61)	(0.32)
Method (*Control*)	−0.0100***	−0.0168***	0.0122**	−0.0185
	(−3.00)	(−3.91)	(2.25)	(−1.57)
Time (*2015*)	−0.1758***	−0.1981***	−0.2002***	−0.2004*
	(−5.84)	(−5.74)	(−2.94)	(−1.76)
Time (*Publish*)	−0.0224***	−0.0283***	−0.0281*	0.0043
	(−2.90)	(−3.05)	(−1.72)	(0.11)
Constant	45.6511***	57.5830***	57.1193*	−8.1576
	(2.92)	(3.07)	(1.73)	(−0.10)
N	941	719	261	136
Adjusted R-squared	0.1123	0.1611	0.1633	0.0891
Tau-square	0.07155	0.08024	0.05579	0.04884
I-square residual (%)	99.95	99.59	99.86	99.99

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; t statistics in parentheses; Adjusted R-squared refers to the proportion of between-study variance explained.

Table 4
Meta-regression results by income group.

	Overall	Social	Economic	Environmental
LICs & *LMICs*	0.0632**	0.0564*	0.0823	0.2352***
	(2.50)	(1.78)	(1.62)	(2.97)
UMICs	0.0463	0.0714**	0.0136	−0.3466
	(1.63)	(2.10)	(0.23)	(−1.50)
EP (*Multi*)	−0.0106	−0.0017	−0.0767	0.0265
	(−0.48)	(−0.06)	(−1.43)	(0.33)
EP (*Score*)	0.0451*	0.0521	0.0143	0.0946
	(1.66)	(1.61)	(0.22)	(0.44)
Method (*Identify*)	0.0285***	0.0400***	−0.0015	−0.0059
	(3.06)	(3.50)	(−0.09)	(−0.24)
Method (*Control*)	−0.0090***	−0.0152***	0.0107*	−0.0202*
	(−2.63)	(−3.43)	(1.82)	(−1.82)
Time (*2015*)	−0.1644***	−0.1997***	−0.2185***	−0.0584
	(−5.07)	(−5.32)	(−3.25)	(−0.49)
Time (*Publish*)	−0.0236***	−0.0295***	−0.0253	−0.0342
	(−3.00)	(−3.16)	(−1.55)	(−0.86)
Constant	47.9183***	59.9865***	51.5115	69.7417
	(3.02)	(3.18)	(1.56)	(0.87)
N	941	719	261	136
Adjusted R-squared	0.1126	0.1617	0.1625	0.1556
Tau-square	0.07135	0.08018	0.05584	0.04528
I-square residual (%)	99.95	99.57	99.78	99.99

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; t statistics in parentheses; Adjusted R-squared refers to the proportion of between-study variance explained.

Compared to HICs, studies in LICs & LMICs find the overall consequences of energy poverty to be much more severe, with the largest and most significant differences observed in environmental consequences. This suggests that energy poverty in poorer economies is more closely linked to environmental impacts, such as higher emissions, reliance on polluting fuels, or environmental degradation, while in high-income contexts, cleaner energy infrastructure and regulatory frameworks may mitigate these impacts. In terms of social consequences, the magnitude of the impact is larger for LICs & LMICs as well as UMICs than for HICs, which suggests that the social consequences of energy poverty, especially the adverse effects on health, well-being, and welfare, are more pronounced outside of high-income contexts. In contrast, the difference in economic impact between different income groups is weaker and not statistically significant, suggesting that the economic consequences of energy poverty may be more targeted and less consistently linked to national income levels.

It is noteworthy that the estimated coefficient for UMICs is not significant for the overall consequences and is negative for the environmental consequences, although it is not statistically significant. This highlights a transition pattern where some middle-income economies may partially decouple energy poverty from environmental pressures. This decoupling observed in UMICs may reflect two competing mechanisms in our analytical framework (Fig. 2). On one hand, economic growth and enhanced investment capacity can facilitate transitions to cleaner fuels, weakening the direct link between energy poverty and local environmental degradation. On the other hand, if such transitions rely on expanding fossil fuel infrastructure, they may generate "carbon lock-in" effects, where long-lived assets perpetuate high-emission pathways. The non-significant environmental coefficients suggest these opposing forces may balance each other within UMICs. Furthermore, the significant social consequences observed in UMICs imply potential rebound effects. As incomes rise and energy services become more affordable, increased consumption may offset efficiency gains, shifting the burden of energy poverty from the environmental sphere to the social sphere. For instance, expanded but still polluting energy use could exacerbate health impacts.

In terms of control variables, the methodological rigor is again associated with larger reported impacts on the overall and social systems, consistent with the finding that more sophisticated empirical strategies better capture the consequences of energy poverty. The estimated coefficients for control variables related to the scope of time, study period, and publication year have the same sign and significance pattern as those reported in Table 3.

4.2.3. Regional group

To further explore geographical heterogeneity beyond income classification, Table 5 reports meta-regression results by regional group, with the baseline including all other regions in the sample. These estimates reveal large regional differences in the consequences of energy poverty.

Of the regions analyzed, SAS shows the most significant positive impact. Energy poverty in SAS is associated with larger overall consequences compared to the baseline, with significant impacts across the social and economic systems. This pattern is consistent with the region's high dependence on traditional energy, continued access constraints, and the close link between energy deprivation. In contrast, SSA shows no statistically significant differences from the baseline across all systems, suggesting greater heterogeneity within the region, or offsetting effects and consequences across countries.

In addition, a different pattern is observed in EAS. While the coefficients for the overall, social, and economic systems are not statistically significant, the environmental system presents a significantly negative result, indicating that the environmental consequences of energy poverty are weaker or even mitigated relative to the baseline. This observed decoupling in EAS provides empirical support for the technology diffusion and stringent policy intervention mechanisms. The region's aggressive renewable energy deployment and pollution control regulations appear to effectively disrupt the traditional mechanism whereby energy poverty forces reliance on polluting fuels. Consequently, even households experiencing energy deprivation may be partially insulated from severe environmental harm.

Regarding the control variables, the estimated coefficients of energy poverty measurement choice, methodological complexity, control strength, post-2015 period effects, and publication year are basically

Table 5
Meta-regression results by regional group.

	Overall	Social	Economic	Environmental
EAS	−0.0087	0.0083	0.0170	−0.3540**
	(−0.39)	(0.29)	(0.40)	(−2.48)
SAS	0.0879***	0.0902***	0.1148**	0.1502
	(3.43)	(2.86)	(1.99)	(1.18)
SSA	0.0079	0.0172	0.0065	−0.0503
	(0.26)	(0.45)	(0.11)	(−0.41)
EP (*Mul*)	−0.0204	−0.0151	−0.0941	0.0271
	(−0.89)	(−0.56)	(−1.53)	(0.34)
EP (*Score*)	0.0544**	0.0621*	0.0053	0.1490
	(2.07)	(1.94)	(0.08)	(0.93)
Method (*Identify*)	0.0281***	0.0409***	0.0006	−0.0091
	(3.00)	(3.51)	(0.03)	(−0.38)
Method (*Control*)	−0.0117***	−0.0177***	0.0074	−0.0059
	(−3.44)	(−4.04)	(1.20)	(−0.47)
Time (*2015*)	−0.1412***	−0.1694***	−0.2024***	−0.2413*
	(−4.41)	(−4.58)	(−2.92)	(−1.66)
Time (*Publish*)	−0.0129	−0.0163*	−0.0031	−0.0544
	(−1.58)	(−1.66)	(−0.17)	(−1.35)
Constant	26.3704	33.2092*	6.7436	110.5641
	(1.60)	(1.67)	(0.19)	(1.35)
N	941	719	261	136
Adjusted R-squared	0.1244	0.1695	0.1709	0.1920
Tau-square	0.07058	0.07944	0.05529	0.04333
I-square residual (%)	99.95	99.57	99.76	99.99

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$; t statistics in parentheses; Adjusted R-squared refers to the proportion of between-study variance explained.

consistent with those in Tables 3 and 4 in terms of sign and statistical significance. These similarities suggest that the observed regional heterogeneity is not driven by differences in study design or publication characteristics, but rather reflects regional differences in how energy poverty translates into different consequences.

In summary, based on the results of the three meta-regressions, it is clear that the consequences of energy poverty exhibit stronger and broader impacts in less developed countries. When countries are grouped by development status, developing economies experience greater overall, social, and economic consequences of energy poverty, while environmental impacts remain statistically insignificant, suggesting that direct welfare and economic mechanisms play a dominant role in these systems. Compared to HICs, energy poverty in LICs & LMICs is associated with greater overall and social consequences, especially environmental impacts, while UMICs primarily demonstrate stronger social impacts. Regional estimates further confirm this heterogeneity, indicating that SAS stands out in terms of overall, social, and economic consequences, while EAS exhibits weaker associations.

5. Discussion

5.1. Other findings

The findings in Section 4 suggest that the consequences of energy poverty are related to income levels or regional characteristics. However, more importantly, these variations also depend on complex mechanisms.

First, energy poverty is not only a shortage of modern energy services, but also a reflection of cumulative disadvantages formed by income constraints, infrastructure gaps, institutional capacity, and social vulnerability. A primary mechanism is the direct socioeconomic cycle, prevalent in environments with limited infrastructure and institutional capacity. In low-income and developing contexts, energy poverty often occurs simultaneously with inadequate housing quality, public health services, and labor market opportunities (Mei and Seo, 2024). Reliance on solid fuels for basic needs directly harms health, while inadequate lighting and digital exclusion constrain educational attainment. They trigger a critical economic mechanism by eroding human capital and labor productivity (Wang et al., 2025). The resulting income constraints then limit households' ability to invest in cleaner, more reliable energy solutions, thereby exacerbating the initial energy deprivation. In contrast, in high-income contexts where basic energy infrastructure is largely available, energy poverty is more closely related to affordability pressures and price volatility (Bednar and Reames, 2020). As a result, its observable social impacts may be weakened, shifting the consequences to mental health or energy insecurity anxiety.

The second explanatory analysis examines the role of institutional and market contexts in shaping the economic consequences of energy poverty, revealing multiple mechanisms beyond direct deprivation effects. In labor markets characterized by weakness, limited social security, and high informality, the direct constraint mechanism predominates. The energy poverty restricts access to productive energy uses such as heating, cooling, and electricity-dependent household businesses, directly constraining income-generating activities (Xiao et al., 2022; Allcott et al., 2016). In contrast, in more developed economies, institutional buffers transform this direct pathway into indirect and often delayed effects. Labor markets and welfare systems may mitigate immediate income shocks, shifting consequences toward long-term vulnerabilities such as debt accumulation or reduced resilience to energy price shocks (Croon et al., 2024; Middlemiss et al., 2023). Furthermore, the interaction between energy poverty and structural economic shifts introduces a distributional effect. As energy price increases associated with decarbonization policies disproportionately burden vulnerable households (Guan et al., 2023), energy poverty transforms from a developmental challenge into a distributional equity issue.

From an environmental perspective, the mechanisms linking energy poverty to ecological outcomes demonstrate even greater diversity. In many low- and middle-income regions, the direct degradation pathway remains primary. The reliance on traditional biomass and inefficient fuels directly drives deforestation and local pollution (Foster et al., 2024; Mundaca et al., 2018), creating simultaneous social and ecological burdens. However, the relationship becomes more complex in advanced economies, where the rebound effect manifests. While energy poverty might force consumption reductions that appear environmentally beneficial, these often occur at the expense of basic well-being (Cong et al., 2022; Castaño-Rosa et al., 2019), representing welfare losses rather than genuine sustainability gains. More importantly, the efficiency rebound, where improved energy access leads to increased consumption that offsets environmental benefits, presents a critical policy challenge, particularly in transitional economies.

5.2. Future research directions

Based on the bibliographic and empirical evidence, future research can be developed in three directions.

First, greater emphasis should be placed on dynamic and longitudinal research designs. The current evidence base relies heavily on cross-sectional data, which limits insights into the persistence of energy poverty, its long-term feedback effects, and the intergenerational or life-course dimensions of its impacts. Future research would benefit from employing panel data, cohort studies, or quasi-experimental methods to examine how energy poverty shapes trajectories in health, education, labor outcomes, and household resilience over time. This is particularly important for evaluating the sustained effectiveness of policy interventions in both developing and developed contexts (Lee and Shon, 2024).

Second, research should broaden its scope to investigate understudied consequences of energy poverty, particularly in environmental and macroeconomic domains (Qurat-ul-Ann and Mirza, 2020; Menyhért, 2024; Delugas and Brau, 2021). While existing literature has extensively examined social and microeconomic outcomes, our findings reveal that environmental impacts remain comparatively underexplored, with notable regional imbalances in evidence. Future studies should integrate energy poverty indicators into climate-economy models, just transition frameworks, and macroeconomic vulnerability assessments, thereby helping to bridge the fragmented research between current social policy, environmental economics, and climate governance.

Third, advancing measurement harmonization and methodological standardization is a key priority in this field. Heterogeneity observed in indicator construction, model specifications, and control strategies complicates cross-study comparability and undermines knowledge accumulation. Future efforts should aim to develop more transparent, comparable, and policy-relevant measurement frameworks through standardized reporting practices, sensitivity analyses, and data sharing. Strengthening methodological consistency will not only enhance the robustness of empirical results, but also strengthen the evidence base needed to inform energy poverty policies in different institutional and regional contexts.

6. Conclusions

This study comprehensively synthesizes the existing empirical evidence on the consequences of energy poverty through a meta-analysis of 119 studies. Across different national contexts, methodologies, and systems, the accumulated evidence suggests that energy poverty is not a limited deprivation confined to household energy access, but a multidimensional challenge with far-reaching social, economic, and environmental impacts. Overall, the findings indicate that energy poverty is associated with adverse welfare outcomes, although the magnitude and manifestation of these consequences vary across income levels, stages of development, and regional contexts. This heterogeneity highlights the importance of avoiding a unified interpretation of energy poverty and recognizing its context-dependent characteristics.

A key finding of the meta-analysis is the heterogeneity in estimated consequences across income groups, regions, and development status. These variations may reflect structural differences in energy systems, institutional capacity, labor markets, and social safety nets. In low-income and developing contexts, energy poverty is often more intertwined with basic welfare deficits, amplifying its social and economic consequences. In contrast, in high-income contexts, energy poverty often manifests as affordability constraints and energy insecurity, which may have more meaningful welfare implications. Regional differences further suggest that climatic conditions, energy structures, and governance frameworks determine how energy poverty translates into observable outcomes. These patterns highlight that the impacts of energy poverty are manifested through multiple mechanisms rather than a single pathway.

The temporal patterns observed in the empirical literature suggest that the understanding of energy poverty and its consequences is evolving. The weakening or decline in effect sizes observed in recent studies may reflect improvements in energy access, policy interventions, and social safety nets in many regions, but also the refinement of concepts and more rigorous empirical identification strategies. At the same time, the post-2015 period coincided with a shift in research from access-oriented definitions to affordability, energy services, and vulnerability perspectives. This evolution suggests energy poverty is increasingly seen as a dynamic, interconnected condition affected by price volatility, energy transitions, and climate policies, rather than simply a lack of infrastructure.

In addition to contextual conditions, methodological choices also play a crucial role in shaping empirical outcomes. Studies that employ more complex econometric techniques tend to report different effect sizes, reflecting better control for confounding factors and greater sensitivity to underlying mechanisms. This pattern suggests that some of the earlier evidence may have overestimated or underestimated certain consequences due to methodological limitations rather than fundamental differences. More broadly, the findings suggest that energy poverty operates through complex pathways, such as health constraints, time allocation, productivity losses, and environmental trade-offs, which are difficult to capture within simplified empirical frameworks.

Meta-analytic evidence indicates that the consequences of energy poverty are highly context-dependent, varying across different stages of development, regions, and measurement methodologies. This heterogeneity implies that standardized, universal policy responses may prove ineffective. In low- and middle-income countries where energy access remains a primary constraint, integrated policies combining electrification and clean cooking initiatives with parallel investments in health, education, and livelihood programs will maximize welfare gains. In contrast, in high-income or energy-rich economies, policy focus should shift toward affordability protection, energy efficiency retrofits, and targeted support for vulnerable households rather than further expanding supply-side capacity.

Furthermore, the analysis identifies critical links between energy poverty and environmental outcomes, along with spillover effects across social and economic domains. This underscores the necessity for cross-sectoral policy coordination. Energy poverty strategies should be explicitly integrated into broader social protection, housing, health, and environmental regulatory frameworks to avoid counterproductive trade-offs. Particularly in the context of rapid decarbonization, proactive measures, such as carefully designed tariff assistance, efficiency subsidies, and transition safeguards, are needed to mitigate the risk that climate policies inadvertently exacerbate energy inequality.

We recognize several limitations to this study. While effect size standardization enables synthesis, it does not imply equivalence across different outcomes. Our findings thus reveal relative patterns in effect strength, not absolute comparability. Inconsistencies in data reporting across countries, particularly between national surveys and household samples, may affect the accuracy of trends. The distribution of existing literature remains uneven, and some consequences, particularly environmental and macroeconomic impacts, remain under-explored. In addition, our focus on quantification has neglected qualitative aspects, and keyword searches may not have fully captured all relevant observations.

CRediT authorship contribution statement

Ruohan Zhong: Writing – original draft, Visualization, Software, Methodology, Data curation, Conceptualization, Writing – review & editing. **Chu Wei:** Supervision, Funding acquisition, Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Appendix figure

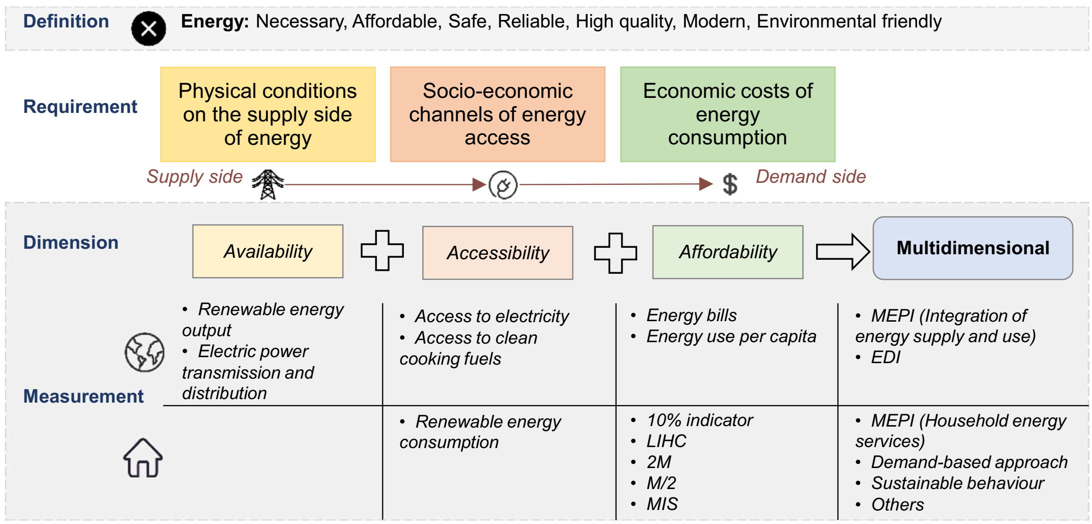

Fig. A.1. The definitions and measurements of energy poverty.

Appendix B. Appendix table

See Tables B.1–B.6.

Table B.1
Meta-regression results by development status (EB).

	Overall	Social	Economic	Environmental
Developing	0.0924**	0.0878**	0.1831**	−0.1315
	(2.51)	(2.01)	(2.16)	(−0.38)
EP (Mul)	−0.0399*	−0.0315	−0.1367***	−0.1222
	(−1.72)	(−1.12)	(−3.17)	(−1.61)
EP (Score)	0.0623**	0.0776***	0.0009	0.1421
	(2.48)	(2.59)	(0.01)	(0.47)
Method (Identify)	0.0351***	0.0448***	0.0135	0.0166
	(3.59)	(3.77)	(0.74)	(0.61)
Method (Control)	−0.0100***	−0.0168***	0.0123**	−0.0166
	(−2.93)	(−3.82)	(2.22)	(−1.29)
Time (2015)	−0.1792***	−0.2019***	−0.1997***	−0.1887
	(−5.82)	(−5.71)	(−2.89)	(−1.52)
Time (Publish)	−0.0231***	−0.0293***	−0.0280*	0.0010
	(−2.91)	(−3.07)	(−1.67)	(0.02)
Constant	46.9981***	59.57366***	56.9725*	−1.4556
	(2.93)	(3.09)	(1.68)	(−0.02)
N	941	719	261	136
Adjusted R-squared	0.1072	0.1500	0.1759	0.0289
Tau-square	0.09462	0.10680	0.07208	0.08411
I-square residual (%)	99.95	99.59	99.86	99.99

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; *t* statistics in parentheses.

Table B.2
Meta-regression results by income group (EB).

	Overall	Social	Economic	Environmental
LICs & LMICs	0.0630**	0.0548*	0.0829	0.2598***
	(2.42)	(1.68)	(1.59)	(3.01)
UMICs	0.0483*	0.0730**	0.0180	−0.3328
	(1.65)	(2.09)	(0.29)	(−1.38)
EP (Mul)	−0.0111	−0.0015	−0.0770	0.0305
	(−0.49)	(−0.06)	(−1.40)	(0.35)
EP (Score)	0.0452	0.0540	0.0075	0.0916
	(1.16)	(1.62)	(0.11)	(0.40)
Method (Identify)	0.0308***	0.0426***	0.0007	0.0006
	(3.21)	(3.62)	(0.04)	(0.02)
Method (Control)	−0.0090**	−0.0153***	0.0109*	−0.0185
	(−2.57)	(−3.35)	(1.81)	(−1.53)
Time (2015)	−0.1686***	−0.2045***	−0.2203***	−0.0336
	(−5.08)	(−5.33)	(−3.23)	(−0.26)
Time (Publish)	−0.0242***	−0.0305***	−0.0245	−0.0411
	(−3.00)	(−3.18)	(−1.46)	(−0.96)
Constant	49.2797***	62.0635***	49.9278	83.6189
	(3.02)	(3.20)	(1.47)	(0.96)
N	941	719	261	136
Adjusted R-squared	0.1064	0.1505	0.1619	0.1253
Tau-square	0.09471	0.10680	0.07330	0.07577
I-square residual (%)	99.95	99.57	99.78	99.99

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; t statistics in parentheses; Adjusted R-squared refers to the proportion of between-study variance explained.

Table B.3
Meta-regression results by regional group (EB).

	Overall	Social	Economic	Environmental
EAS	−0.0074	0.0098	0.0195	−0.3611**
	(−0.33)	(0.34)	(0.44)	(−2.31)
SAS	0.0871***	0.0892***	0.1133*	0.1553
	(3.30)	(2.75)	(1.90)	(1.12)
SSA	0.0093	0.0177	0.0086	−0.0238
	(0.30)	(0.45)	(0.14)	(−0.18)
EP (Mul)	−0.0207	−0.0149	−0.0948	0.0364
	(−0.87)	(−0.53)	(−1.50)	(0.42)
EP (Score)	0.0548**	0.0641*	0.0003	0.1577
	(2.02)	(1.94)	(0.00)	(0.91)
Method (Identify)	0.0303***	0.0434***	0.0028	−0.0032
	(3.14)	(3.62)	(0.16)	(−0.12)
Method (Control)	−0.0118***	−0.0178***	0.0077	−0.0041
	(−3.35)	(−3.94)	(1.21)	(−0.30)
Time (2015)	−0.1453***	−0.1738***	−0.2030***	−0.2124
	(−4.43)	(−4.59)	(−2.87)	(−1.36)
Time (Publish)	−0.0136	−0.0173*	−0.0023	−0.0636
	(−1.62)	(−1.72)	(−0.13)	(−1.45)
Constant	27.8036	35.3940*	5.0945	129.1911
	(1.64)	(1.73)	(0.14)	(1.46)
N	941	719	261	136
Adjusted R-squared	0.1130	0.1541	0.1682	0.1618
Tau-square	0.09401	0.10630	0.07275	0.07260
I-square residual (%)	99.95	99.57	99.76	99.99

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; t statistics in parentheses; Adjusted R-squared refers to the proportion of between-study variance explained.

Table B.4
Meta-regression results by development status (OLS and WLS).

	Overall		Social		Economic		Environmental	
	OLS	WLS	OLS	WLS	OLS	WLS	OLS	WLS
Developing	0.1418***	0.0872***	0.1180**	0.1019***	0.4047***	0.2113	−0.0591	−0.1758
	(3.40)	(2.65)	(2.51)	(3.30)	(3.43)	(1.63)	(−0.28)	(−0.88)
EP (*Mul*)	−0.0637**	−0.0115	−0.0455	−0.0169	−0.1978***	−0.2220***	−0.3194*	−0.3176*
	(−2.17)	(−0.33)	(−1.35)	(−0.47)	(−3.58)	(−3.69)	(−1.90)	(−1.80)
EP (*Score*)	0.0742**	0.0583*	0.1037***	0.0627*	−0.0571	−0.0028	0.3517**	0.4027**
	(2.35)	(1.74)	(2.89)	(1.65)	(−0.64)	(−0.03)	(2.33)	(2.33)
Method (*Identify*)	0.0635***	0.0422***	0.0704***	0.0509***	0.0818**	0.0119	0.1051**	0.0952**
	(5.03)	(3.57)	(4.62)	(3.99)	(2.49)	(0.39)	(2.12)	(2.14)
Method (*Control*)	−0.0104**	−0.0162***	−0.0174***	−0.0191***	0.0148	0.0020	−0.0028	−0.0085
	(−2.28)	(−4.24)	(−2.83)	(−4.24)	(1.60)	(0.31)	(−0.09)	(−0.32)
Time (*2015*)	−0.1869***	−0.2601***	−0.2071***	−0.3089***	−0.1194	0.0642	−0.2000	−0.2243
	(−4.87)	(−4.68)	(−4.90)	(−5.76)	(−1.18)	(0.48)	(−1.33)	(−1.43)
Time (*Publish*)	−0.0328***	−0.0136	−0.0419***	−0.0268***	−0.0285	0.0016	−0.0978	−0.1215
	(−2.90)	(−1.51)	(−3.08)	(−3.05)	(−1.54)	(0.06)	(−1.05)	(−1.18)
Constant	66.5274***	27.8961	85.0884***	54.5255***	57.4778	−3.0520	197.9545	246.0086
	(2.91)	(1.53)	(3.10)	(3.08)	(1.54)	(−0.06)	(1.05)	(1.18)
N	941	941	719	719	261	261	136	136
R-Squared	0.0829	0.1335	0.1092	0.1729	0.1335	0.0701	0.0977	0.1003

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$; t statistics in parentheses.

Table B.5
Meta-regression results by income group (OLS and WLS).

	Overall		Social		Economic		Environmental	
	OLS	WLS	OLS	WLS	OLS	WLS	OLS	WLS
LICs & *LMICs*	0.0791**	0.0865***	0.0779	0.0827**	0.0511	0.1320	0.4454***	0.4636***
	(2.02)	(2.60)	(1.64)	(2.20)	(0.56)	(1.46)	(3.19)	(3.15)
UMICs	0.0832***	0.1078***	0.1108***	0.1426***	0.0932	0.0716	−0.2625	−0.5612**
	(2.60)	(3.57)	(2.94)	(4.98)	(1.17)	(0.88)	(−1.27)	(−2.07)
EP (*Mul*)	−0.0189	0.0091	−0.0023	0.0122	−0.1464	−0.1290	−0.0659	−0.0388
	(−0.67)	(0.32)	(−0.07)	(0.39)	(−1.62)	(−1.36)	(−0.38)	(−0.21)
EP (*Score*)	0.0501	0.0338	0.0671*	0.0386	0.0072	−0.0543	0.1535	0.3214
	(1.45)	(0.99)	(1.74)	(1.01)	(0.06)	(−0.44)	(0.68)	(1.52)
Method (*Identify*)	0.0581***	0.0435***	0.0684***	0.0533***	0.0605*	−0.0108	0.0813*	0.0768*
	(4.74)	(3.84)	(4.57)	(4.34)	(1.93)	(−0.42)	(1.82)	(1.91)
Method (*Control*)	−0.0090*	−0.0141***	−0.0149**	−0.0171***	0.0157	0.0009	−0.0053	−0.0107
	(−1.95)	(−3.87)	(−2.45)	(−3.98)	(1.47)	(0.13)	(−0.17)	(−0.41)
Time (*2015*)	−0.1813***	−0.2582***	−0.2117***	−0.3213***	−0.1855*	−0.0030	0.0646	0.0628
	(−4.14)	(−4.18)	(−4.36)	(−5.52)	(−1.96)	(−0.03)	(0.35)	(0.33)
Time (*Publish*)	−0.0340***	−0.0183**	−0.0446***	−0.0322***	−0.0112	0.0029	−0.1680*	−0.1956*
	(−2.84)	(−1.98)	(−3.17)	(−3.56)	(−0.58)	(0.12)	(−1.89)	(−1.92)
Constant	69.0378***	37.3915**	90.4244***	65.5619***	22.8738	−5.5840	339.9204*	395.8287*
	(2.86)	(2.00)	(3.18)	(3.59)	(0.58)	(−0.11)	(1.89)	(1.92)
N	941	941	719	719	261	261	136	136
R-Squared	0.0820	0.1435	0.1125	0.1888	0.1036	0.0591	0.1601	0.1586

Notes: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$; t statistics in parentheses.

Table B.6
Meta-regression results by regional group (OLS and WLS).

	Overall		Social		Economic		Environmental	
	OLS	WLS	OLS	WLS	OLS	WLS	OLS	WLS
EAS	0.0056	−0.0346	0.0262	−0.0247	0.0628	0.1085*	−0.4468***	−0.5185***
	(0.18)	(−0.99)	(0.63)	(−0.53)	(1.06)	(1.68)	(−3.08)	(−3.63)
SAS	0.0856**	0.0940**	0.0954**	0.0859	−0.0079	0.1628**	0.1164	0.1526
	(2.24)	(2.11)	(1.97)	(1.60)	(−0.08)	(2.14)	(0.67)	(0.79)
SSA	0.0266	−0.0326	0.0430	−0.0110	0.0280	0.0146	0.1764	0.0846
	(0.63)	(−0.61)	(0.86)	(−0.16)	(0.26)	(0.13)	(1.17)	(0.73)
EP (*Mul*)	−0.0307	−0.0197	−0.0150	−0.0142	−0.1900	−0.1945	−0.0173	−0.0044
	(−1.05)	(−0.68)	(−0.48)	(−0.46)	(−1.64)	(−1.59)	(−0.10)	(−0.02)
EP (*Score*)	0.0698**	0.0723**	0.0842**	0.0704*	0.0586	−0.0292	0.3231	0.3391
	(2.01)	(2.01)	(2.06)	(1.71)	(0.47)	(−0.22)	(1.36)	(1.56)
Method (*Identify*)	0.0562***	0.0401***	0.0676***	0.0479***	0.0611**	0.0013	0.0683*	0.0636*
	(4.61)	(3.57)	(4.50)	(3.69)	(2.01)	(0.05)	(1.69)	(1.72)
Method (*Control*)	−0.0124***	−0.0171***	−0.0182***	−0.0189***	0.0151	−0.0013	0.0163	0.0153
	(−2.63)	(−4.16)	(−3.00)	(−3.88)	(1.21)	(−0.17)	(0.46)	(0.50)
Time (*2015*)	−0.1581***	−0.2279***	−0.1807***	−0.2737***	−0.1794**	0.0093	−0.1884	−0.2517
	(−3.74)	(−4.18)	(−4.01)	(−5.14)	(−2.00)	(0.09)	(−0.55)	(−0.75)
Time (*Publish*)	−0.0212**	−0.0012	−0.0286**	−0.0121	−0.0004	0.0324	−0.2188**	−0.2295**
	(−2.01)	(−0.15)	(−2.45)	(−1.38)	(−0.01)	(1.11)	(−2.20)	(−2.16)
Constant	43.2335**	2.9046	58.1050**	24.9916	0.9866	−65.1857	442.8510**	464.6564**
	(2.03)	(0.18)	(2.47)	(1.41)	(0.02)	(−1.10)	(2.20)	(2.16)
N	941	941	719	719	261	261	136	136
R-Squared	0.0823	0.1390	0.1122	0.1721	0.1026	0.0785	0.2107	0.2055

Notes: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; t statistics in parentheses.

Data availability

The bibliographic data and analysis tables used for the meta-analysis that support the results of this study can be found in https://github.com/RuohanZhong/List-of-studies-for-meta-analysis-of-energy-poverty

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