Understanding Energy Poverty in the Global North: A Panel Data Investigation

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Theme: Current and Future Challenges to Energy Security

Presentation Outline

Understanding Energy Poverty in the Global North

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2 Literature Review

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Conceptualization, price effects, income and inequality, social protection, structural factors, and methodological approaches

3 Research Design

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Research gaps, objectives, 8-country sample (Australia, Canada, France, Germany, Italy, Mexico, UK, US), and 34-year timeframe

4 Methodology

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Conceptual framework, Energy Affordability Ratio (EAR), key variables, and econometric approaches (RE, FE, 2SIV, MGIV)

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Descriptive statistics, correlations, dynamic coefficients, trends, and key findings on price effects, income, inequality, social protection, and structural factors

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Summary of key findings, significance for energy security and affordability, and implications for developed economies during energy transitions

Introduction: Energy Poverty in the Global North

Evolution, crises, and cross-country perspectives

Context & Evolution

- Energy poverty now urgent in developed economies despite infrastructure access
- 2008 financial crisis and 2021-2022 energy crises intensified affordability pressures
- Global South vs. North: physical access vs. affordability and adequacy
- Terms: "fuel poverty" (EU) vs. "high energy burden" (North America)

Evidence & Disparities

- UK: ~13% fuel poor households
- Australia: 8-15% energy-poor (methodology dependent)
- US: Low-income households spend up to 15% of income on energy
- EU: Southern/Eastern regions more affected than Nordic countries

Determinants & Research Gaps

- Beyond income: Energy prices, dwelling efficiency, climate needs
- Social factors: Inequality, unemployment, welfare regimes
- Limitations in existing research:
  - Single-country focus limits comparison
  - Methodological diversity complicates frameworks
  - Endogeneity between prices and policies often ignored
  - Parameter homogeneity assumed despite contextual differences

This Study's Scope

- 8 countries: Australia, Canada, France, Germany, Italy, Mexico, UK, US
- Period: 1990-2023 (34 years, balanced panel)
- Outcome: Energy Affordability Ratio (EAR)
- Methods: RE, FE, 2SIV, MGIV addressing endogeneity and heterogeneity
- Goal: Identify effective policy mechanisms balancing pricing with targeted support

Literature Review: Key Themes and Evidence

Evolving perspectives on energy poverty in developed economies

Conceptualization

- Multidimensional issue spanning affordability, access, and quality (Bouzarovski, 2014; Thomson et al., 2017)
- "Triangle of vulnerability": low income + high prices + inefficient housing (Bouzarovski, 2014)
- Capability approach: inability to achieve basic functionings (Nussbaumer et al., 2012)

Price Effects

- Price inelasticity in low-income households (Charlier & Kahouli, 2019)
- 1% price increase → +2.7pp energy poverty risk (Churchill & Smyth, 2021)
- Endogeneity between prices and policies requires IV methods

Income & Inequality

- Higher inequality correlates with increased energy poverty (Galvin, 2019)
- U-shaped relationship between inequality and energy poverty (Nguyen & Nasir, 2021)
- Governance quality moderates inequality effects (Acheampong et al., 2022)

Social Protection

- Means-tested transfers outperform untargeted subsidies (Fankhauser & Tepic, 2007)

Structural & Climate Factors

- Housing quality impacts energy needs as much as income (Okushima, 2017)
- Extreme temperatures intensify energy burdens (Churchill et al., 2022)
- Larger floor areas increase energy demand despite efficiency (Ellsworth-Krebs, 2020)
- Climate change expanding cooling needs in Southern Europe (Thomson et al., 2019)

Macroeconomic Conditions

- Bidirectional causality between energy poverty and economic growth (Doğanalp et al., 2021)
- Unemployment strongly predicts energy poverty (Lisicki et al., 2024)
- Regional labor markets influence spatial disparities (Jové-Llopis & Trujillo-Baute, 2024)

Methodological Advances

- Evolution from expenditure thresholds to multidimensional metrics (Charlier & Legendre, 2021)
- Advanced econometrics for endogeneity & heterogeneity: Instrumental Variables (IV), system-GMM Mean-group estimators (Churchill & Smyth, 2021; Krishnamurthy & Kriström, 2015)
- Research gap: limited cross-national (non-European) studies → addressed by this paper

Research Gaps and Objectives

Addressing limitations in energy poverty literature

Gaps in Literature

Predominantly single-country studies; limited cross-national comparability

Methodological inconsistency; measures vary widely across research

Endogeneity between prices and policies often ignored in estimation

Parameter homogeneity assumed despite institutional and climatic heterogeneity

Study Objectives

Provide cross-national evidence for 8 developed economies (1990–2023)

Address endogeneity and common shocks through instrumental variables

Capture cross-country slope heterogeneity with mean-group estimation

Identify policy mechanisms to mitigate affordability pressures

Study Sample and Scope

Cross-national panel of developed economies (1990–2023)

The analysis employs a balanced panel dataset spanning 34 years across eight developed economies, selected to represent diverse welfare regimes, energy systems, and institutional contexts.

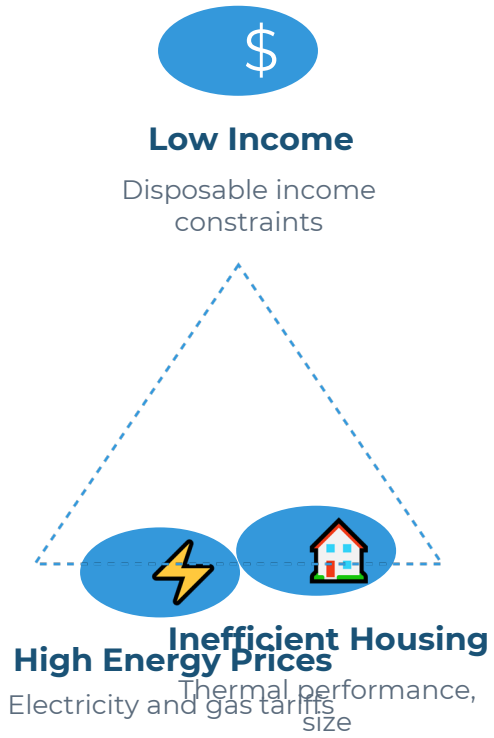
Country	Region	Period	Welfare Model	Energy System
Australia	Oceania	1990–2023	Liberal	Coal/Gas dominant
Canada	North America	1990–2023	Liberal	Hydro/Gas
France	Europe	1990–2023	Conservative	Nuclear dominant
Germany	Europe	1990–2023	Conservative	Coal/Renewables
Italy	Europe	1990–2023	Mediterranean	Gas dominant
United Kingdom	Europe	1990–2023	Liberal	Gas/Renewables
United States	North America	1990–2023	Liberal	Gas/Coal
Mexico	North America	1990–2023	Developing	Oil/Gas dominant

Table 1: Study sample characteristics and institutional context

Conceptual Framework

Triangle of Vulnerability and Energy Affordability Ratio

Energy poverty in developed economies emerges from the interaction between three key drivers, forming a "triangle of vulnerability" that determines household affordability outcomes.



Energy Affordability Ratio (EAR) = (Electricity Price × Residential Electricity Use) / Disposable Income

Higher EAR indicates worse affordability. The metric captures how price shocks, consumption needs, and income constraints interact to determine household energy burden.

Figure 1: The triangle of vulnerability and Energy Affordability Ratio (EAR) measurement approach

Key Variables

Dependent, explanatory, and control variables

The analysis employs a comprehensive set of variables to capture energy affordability determinants across developed economies, with the Energy Affordability Ratio (EAR) as the primary outcome measure.

Variable	Symbol	Unit / Scale	Definition / Construction
Dependent Variable			
Energy Affordability Ratio	EAR	Share (0–1)	(ELECTPR × RESENR) / DI (electricity budget share)
Main Explanatory Variables			
Electricity Price	ELECTPR	USD/kWh	End-user retail electricity tariff
Gas Price	GSPRICE	USD/unit	End-user retail gas tariff (harmonized)
Energy Price Index	CPIENRGY	Index (base=100)	Energy price index; proxy for inflation
Control Variables			
Disposable Income	DI	USD/person	After-tax disposable income (real)
Income Inequality	GINI	Index (0-100)	Gini coefficient of income inequality
Social Spending	SOCSPND	% of GDP	Social protection expenditure

Methodology Overview

Econometric approaches to addressing endogeneity and heterogeneity

Estimation Approaches

Random Effects (RE): Baseline associations with country-specific random intercepts

Fixed Effects (FE): Exploits within-country variation with time and country fixed effects

Two-Stage IV (2SIV): Addresses endogeneity through defactoring and instrumental variables

Mean-Group IV (MGIV): Allows for country-specific slope heterogeneity while correcting for endogeneity

Methodological Rationale

Prices and policies are endogenous due to simultaneity and policy feedback loops

Integration of energy markets creates cross-sectional dependence through common shocks

Heterogeneous institutions, tariff designs, and housing stock require flexible parameter estimation

Progression from RE/FE to 2SIV/MGIV isolates causal effects while revealing cross-country differences

Descriptive Statistics (1990–2023)

Panel data characteristics across 8 countries

The balanced panel dataset (N=272) shows substantial variation in energy prices, income, inequality, and social spending across countries and over time, providing sufficient heterogeneity for meaningful econometric estimation.

Variable	Obs	Mean	Std. Dev.	Min	Max
Energy Affordability Ratio (EAR)	272	0.059	0.291	0.006	3.985
Electricity Price (USD/kWh)	272	4.244	7.256	0.06	32.8
Gas Price	272	0.47	0.688	0.04	3.8
Disposable Income per Capita	272	27,853.76	13,661.04	4,200	81,330
GINI Coefficient	272	35.651	6.211	28	54.5
Social Spending (% GDP)	272	21.025	6.534	6.5	34.1
Heating Degree Days	272	2,770.75	1,103.66	800	4,920

Table 2: Descriptive statistics of key variables in the panel dataset (8 countries, 1990-2023)

Pairwise Correlations

Panel data correlations (1990–2023, N=272)

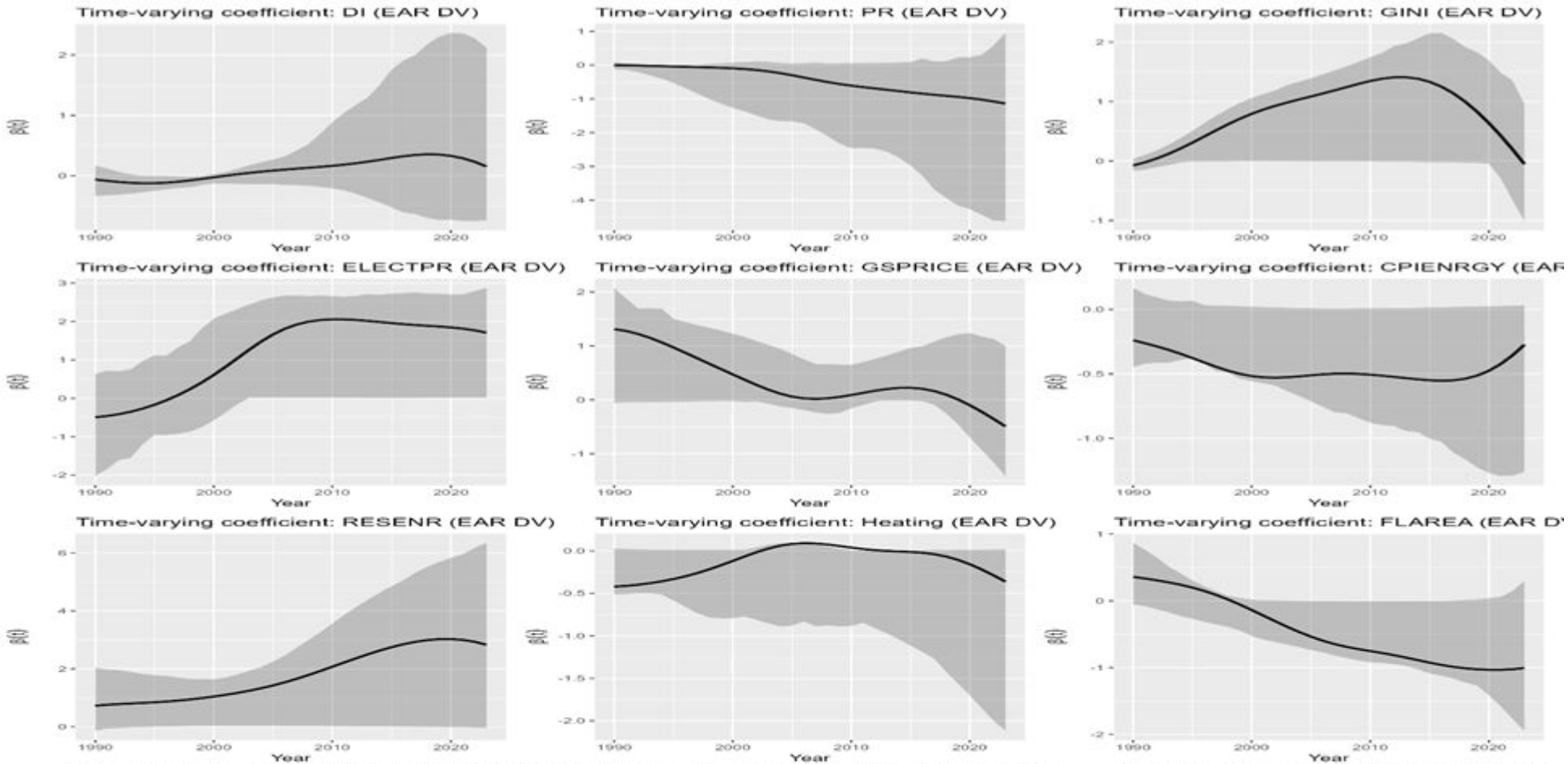
The correlation matrix reveals key relationships among socioeconomic, structural, and energy variables, highlighting strong associations between prices, affordability, and macro indicators.

Variables	DI	PR	GINI	ELECTPR	GSPRICE	CPIENRGY	RESENR	Heating	FLAREA	SOCSPND	UNEMP	URBPOP	GDP	EAR	Affindex
DI	1.000	-0.711***	-0.337***	0.474***	0.103*	0.064	-0.188***	0.575***	0.580***	0.231***	-0.097*	0.303***	0.842***	0.023	-0.725***
PR	-0.711***	1.000	0.650***	-0.379***	-0.022	0.127**	0.095	-0.713***	-0.467***	-0.446***	-0.241***	-0.151**	-0.637***	0.011	0.939***
GINI	-0.337***	0.650***	1.000	-0.064	-0.058	-0.228***	-0.340***	-0.403***	-0.250***	-0.763***	-0.519***	-0.113*	-0.437***	-0.016	0.709***
ELECTPR	0.474***	-0.379***	-0.064	1.000	0.727***	-0.307***	-0.625***	0.117*	0.218***	-0.136**	-0.314***	0.533***	0.429***	0.347***	-0.372***
GSPRICE	0.103*	-0.022	-0.058	0.727***	1.000	-0.096	-0.407***	-0.218***	0.141**	-0.004	-0.237***	0.446***	0.273***	0.483***	-0.089
CPIENRGY	0.064	0.127**	-0.228***	-0.307***	-0.096	1.000	0.591***	-0.156**	0.058	0.438***	0.049	-0.113*	0.186***	-0.025	0.174***
RESENR	-0.188***	0.095	-0.340***	-0.625***	-0.407***	0.591***	1.000	0.155**	0.214***	0.350***	0.397***	-0.254***	-0.023	0.066	0.057
Heating	0.575***	-0.713***	-0.403***	0.117*	-0.218***	-0.156**	0.155**	1.000	0.615***	0.237***	0.205***	0.082	0.483***	-0.004	-0.708***
FLAREA	0.580***	-0.467***	-0.250***	0.218***	0.141**	0.058	0.214***	0.615***	1.000	0.010	-0.084	0.362***	0.698***	0.089	-0.523**
SOCSPND	0.231***	-0.446***	-0.763***	-0.136**	-0.004	0.438***	0.350***	0.237***	0.010	1.000	0.543***	-0.176***	0.377***	0.031	-0.496***
UNEMP	-0.097*	-0.241***	-0.519***	-0.314***	-0.237***	0.049	0.397***	0.205***	-0.084	0.543***	1.000	-0.443***	-0.079	-0.091	-0.333***
URBPOP	0.303***	-0.151**	-0.113*	0.533***	0.446***	-0.113*	-0.254***	0.082	0.362***	-0.176***	-0.443***	1.000	0.416***	0.185***	-0.138**
GDP	0.842***	-0.637***	-0.437***	0.429***	0.273***	0.186***	-0.023	0.483***	0.698***	0.377***	-0.079	0.416***	1.000	0.116*	-0.676***
EAR	0.023	0.011	-0.016	0.347***	0.483***	-0.025	0.066	-0.004	0.089	0.031	-0.091	0.185***	0.116*	1.000	-0.042

Figure 2. LLDVE: Common Trend & Dynamic Coefficients

Time-varying effects of key determinants on energy affordability (1990–2023)

The Locally Linear Dynamic Varying Coefficient (LLDVE) method captures how the impact of explanatory variables on the Energy Affordability Ratio (EAR) changes over time. Solid lines show estimated coefficients; shaded areas represent 95% confidence intervals.



Energy Affordability Trends

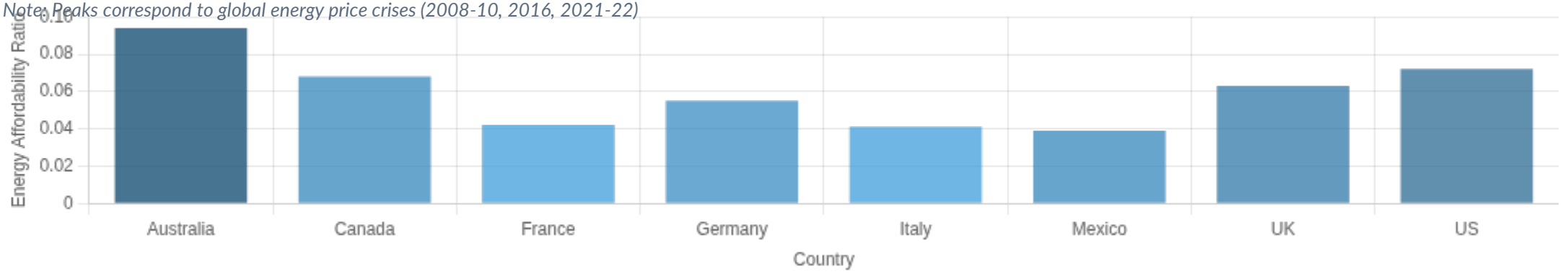
Temporal and Cross-Country Patterns (1990–2023)

Analysis of the Energy Affordability Ratio (EAR) reveals distinct temporal patterns and significant cross-country variations. Notable spikes occurred around 2010 and 2016, coinciding with global energy price volatility and policy adjustments.

Figure 1a: EAR Trends Over Time (1990-2023)

Note: Peaks correspond to global energy price crises (2008-10, 2016, 2021-22)

Figure 1b: Average EAR by Country



Note: Australia exhibits highest average EAR; Mexico, Italy, and France show lower values

Figure 1: Energy Affordability Ratio temporal trends and country-specific patterns

Estimation Results Overview

Comparing Four Econometric Models: RE, FE, 2SIV, MGIV

Table 2 presents key coefficients across four complementary models. Note how price effects attenuate under IV correction while inequality effects strengthen, suggesting endogeneity bias in naive estimates.

Variables	RE	FE	2SIV	MGIV
ln_electricity price	0.093	0.080	0.039	0.080
ln_gas price	0.134	0.159	0.005	0.005
ln_disposable income	0.078	0.168	0.088	0.086
Poverty Rate	-0.001	-0.001	0.003	0.015
GINI	0.018	0.015	0.025	
Energy CPI	-0.001	0.000	-0.004	-0.002
Residential energy	0.000	0.020	0.060	0.070
Heating degree days	0.000	0.010	-0.000	-0.000
Floor area/person	-0.009	-0.008	-0.004	0.002
Social spending	0.019	0.027	0.029	0.007

Key Findings: Price Effects

Electricity and gas price impacts on energy affordability

Electricity Price Effects

Higher electricity prices significantly increase EAR across all models (RE, FE, 2SIV, MGIV)

Causal effects (2SIV) are smaller than naïve estimates (RE/FE), confirming price endogeneity

Price coefficient attenuates from 0.08-0.09 (RE/FE) to 0.039 (2SIV)

Suggests policy feedback and simultaneity bias in naïve models

Gas Price & Energy Demand

Gas price effects diminish under IV and MGIV approaches (0.159 → 0.005)

Energy demand is price-inelastic in the short run

Budget shares move more strongly than consumption quantities

Consumers respond more to average prices than marginal costs

Policy endogeneity explains attenuation (emergency supports, tariff adjustments)

Key Findings: Income and Inequality

Distributional dimensions of energy affordability

Income Effects

Higher real disposable income significantly improves affordability (lowers EAR)

Income growth acts as primary buffer against energy price shocks

Effect remains robust across RE, FE, and 2SIV models

Income coefficients: RE (.078**), FE (.168***), 2SIV (.088)

Labor Market Dynamics

Unemployment coefficient turns negative in 2SIV (−0.024*)

Suggests labor-market conditions operate through distributional channels

Targeted support programs often focus on unemployed households

Inequality Impacts

Greater income inequality (higher Gini) associated with worse affordability

Effect strengthens when correcting for endogeneity

Gini coefficients: RE (.018***), FE (.015***), 2SIV (.025*)

Suggests unequal income distribution heightens vulnerability to energy price increases

MGIV shows weaker average Gini effect (−0.012), indicating important cross-country heterogeneity

Confirms energy poverty is fundamentally a distributional challenge, not merely a macroeconomic one

Key Findings: Social Protection

The role of welfare policies in mitigating energy affordability challenges

Buffer Mechanisms

- Social spending significantly buffers households against energy price shocks
- Social protection coefficient positive and significant across all models (0.029 in 2SIV)
- Income supports sustain purchasing power during market volatility
- Energy-specific transfers (heating allowances, bill supports) provide direct relief

Policy Design Implications

- Targeted transfers outperform broad price suppression measures
  - Higher efficiency in reaching vulnerable households
  - Preserves market signals for consumption decisions
- Policy effectiveness varies by:
  - Welfare regime (Nordic vs. Southern European models)
  - Tariff design (progressive vs. flat-rate structures)
  - Delivery mechanisms (automatic vs. application-based)

Key Findings: Structural and Environmental Factors

Housing, climate, and built environment impacts on energy affordability

Housing Characteristics

- Dwelling quality and thermal efficiency significantly influence required energy consumption
- Larger floor area per person raises energy demand despite efficiency improvements ("rebound effect")
- Housing characteristics mediate how prices and income translate into affordability outcomes
- Housing stock quality explains part of cross-country heterogeneity in price effects

Climate and Structural Factors

- Heating Degree Days (HDD) increase thermally required consumption, raising EAR
- Climate change introduces growing cooling needs, particularly in Southern regions
- Residential electricity use intensity shapes baseline energy requirements
- Urban population density may create efficiency gains through smaller dwellings and shared infrastructure

Theoretical and Methodological Contributions

Advancing energy poverty research through rigorous econometric design

Methodological Innovations

- Integration of RE/FE with 2SIV/MGIV to address both unobserved heterogeneity and endogeneity
- Novel defactoring strategy for common shocks identification and removal
- Simultaneous correction for price-policy endogeneity and cross-sectional dependence
- Systematic transition from pooled to heterogeneous parameter models

Empirical Contributions

- Cross-country evidence spanning beyond Europe, including Australia, US, Canada, and Mexico
- Three-decade panel (1990-2023) capturing multiple energy price cycles
- Framing energy poverty as structural and distributional phenomenon embedded in institutions
- Identification of causal mechanisms linking market, policy, and distributional variables

Policy Implications

Effective strategies for addressing energy poverty in developed economies

Policy Recommendations

- Pair cost-reflective pricing with targeted, means-tested income supports
- Design progressive tariff structures to protect vulnerable consumers
- Invest in residential energy efficiency to reduce structural needs
- Implement temporary bill relief during price shocks

Implementation Considerations

- Customize policy packages to national contexts (welfare regimes, energy mix, housing stock)
- Balance market efficiency with social protection goals
- Prioritize energy efficiency in low-income and rental housing
- Develop adaptive support mechanisms that respond to price volatility

Limitations and Future Research

Addressing constraints and expanding the research agenda

Study Limitations

Sample limited to 8 countries despite global variation in energy poverty

EAR based on electricity budget share only (conservative vs. total energy burden)

Panel approach may not capture all country-specific institutional features

Data harmonization challenges across different measurement systems

Future Research Directions

Expand country coverage to include more welfare regimes and energy systems

Incorporate gas and heating fuels explicitly in affordability metrics

Include emerging cooling needs due to climate change

Explore dynamic effects and policy interactions over time

Develop threshold models to identify non-linear relationships between drivers

Conclusions

Key findings and implications for energy security

Research Findings

Energy poverty in developed economies is fundamentally a structural and distributional phenomenon

Prices significantly impact affordability, but effects are heterogeneous across countries and welfare regimes

Cross-country variation reflects differences in tariff design, housing stock, and institutional frameworks

Policy Considerations

Income growth and targeted social protection are central shock absorbers during price crises

Efficient energy transitions require affordability-focused policy packages

Context-specific approaches must align with energy security priorities and local institutional capacity

Cost-reflective pricing paired with targeted support outperforms broad price suppression

Thank You

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Questions are welcome

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