CASA0007 Assessment Submission

2025-12-30

Declaration of Authorship

Date: 12 January 2026 (Tues)

Student Number: 25049107

I, Tee Chin Min Benjamin, pledge my honour that the work presented in this assessment is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work. ChatGPT has been used to sharpen the language and terms used in the article and support the development of the customized graphics used in this report.

Source code and data can be found at the attached (https://github.com/benjamintee/CASA_QM_Assessment)

HTML version can be found at the attached (https://benjamintee.github.io/CASA_QM_Assessment/Energy_Cost.html)

England's energy crisis is no longer about volatility - it's about persistence and inequality.

Date: 12 Jan 2026

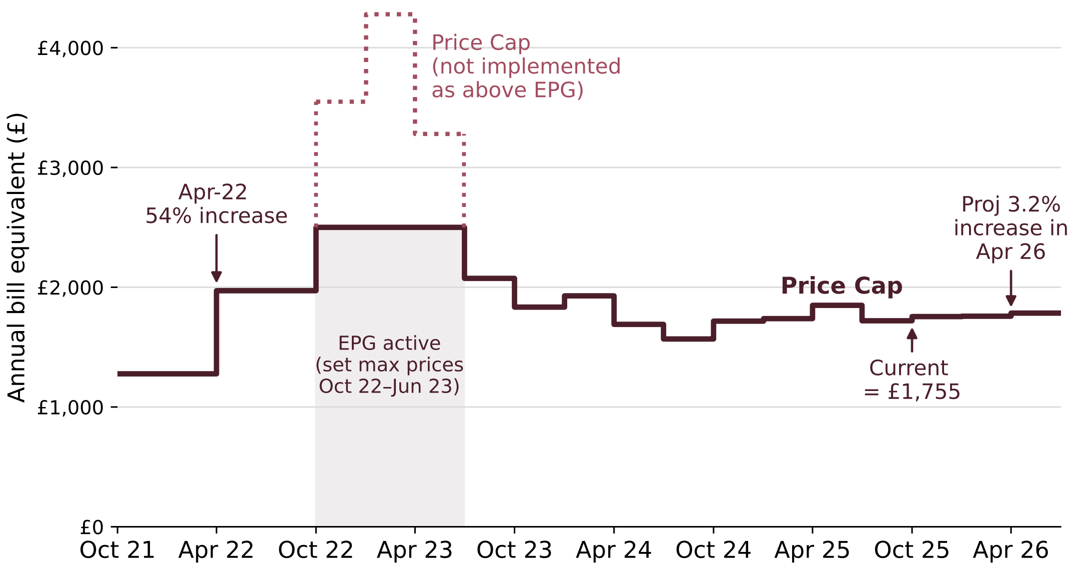
While headline energy prices have eased since 2022, household energy bills in England remain above pre-crisis levels. What has emerged is not a short-lived shock, but a sustained financial burden. When high energy costs persist, they begin to shape household finances and regional inequalities. Understanding who is most exposed, and why, is central to designing effective energy policy.

From shock to persistence

The sharp rise in energy cost in 2022 was driven by global wholesale gas prices and exacerbated by geopolitical shocks[1]. Since then, wholesale prices have moderated. The government's Energy Price Guarantee (EPG) temporarily also capped household exposure at the height of the crisis[2].

Yet, this has not returned household bills to pre-2021 norms. Latest estimates show that the energy price cap remains around £600 (45%) higher than before the crisis (Figure 1). Moreover, the cap is projected to rise again in the coming quarters[3]. While volatility has eased, prices have settled at historically high levels.

Figure 1: The energy price cap has moderated from the period of Energy Price Guarantee (EPG), but remains elevated relative to pre-crisis levels



Source: Ofgem, Cornwall Insights. The energy price cap is the maximum amount energy suppliers can charge households on a standard variable tariff. Price cap based on typical household energy use.

This persistence places growing pressure on households. Average levels of energy debt and the number of households in arrears have risen sharply since 2021 (Figure 2),

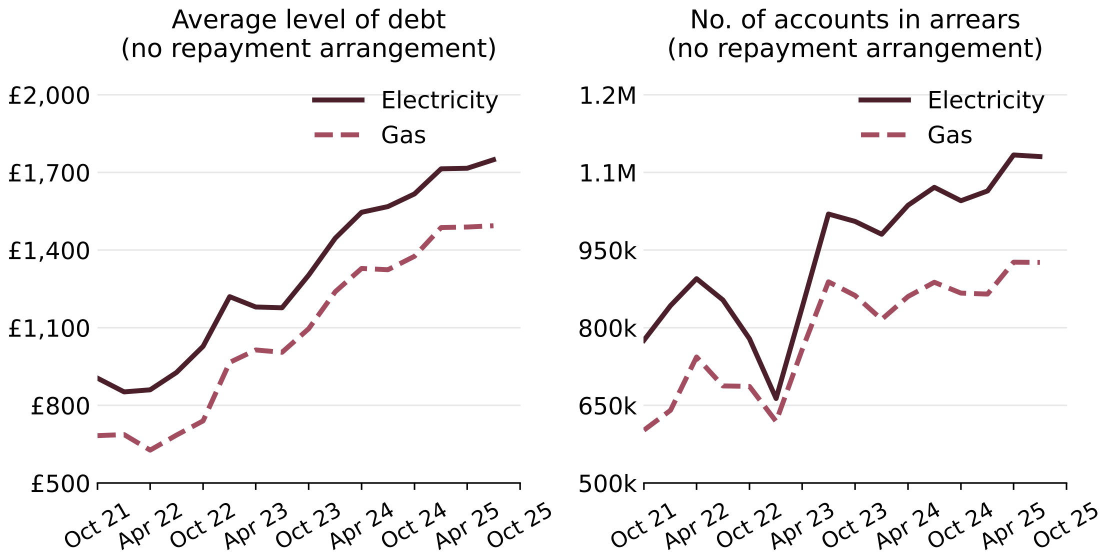
[1] Russia-Ukraine War (Bolton, 2025)

[2] In Sep 22, then-Prime Minister Elizabeth Truss implemented the Energy Price Guarantee (EPG) to cap the typical UK household energy bill at £2,500 a year for the next two years (Prime Minister's Office, 2022).

[3] Cornwall insights forecasts that the price cap for energy bills is expected to rise by 3.2% in 2Q26, to account for increases in network costs for electricity (Cornwall Insights, 2025).

suggesting that many have been unable to absorb higher costs through behavioural adjustments or savings alone (Ofgem, 2025a).

Figure 2: Average debt levels and no. of households in arrears are at an all-time high, suggesting that many households are unable to fully absorb higher costs through short-term adjustments alone.

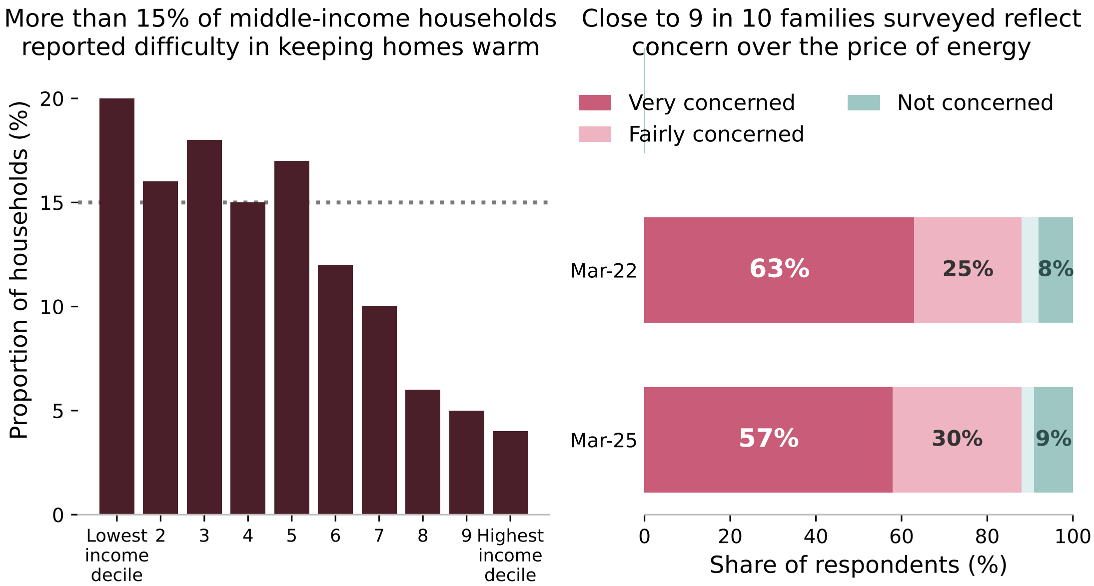


Source: Ofgem data. Information accurate as of Dec 2025.

While the impact is most acute for lower-income households, higher energy costs are also squeezing the broad-middle. At least 15% of middle-income households now report struggling to heat their homes adequately (Tilly Cook, 2025). It is therefore unsurprising that energy costs remain at the top of public concerns. A March 2025 IPSOS UK survey[4] found that close to nine in ten respondents (88%) were worried about the price households pay for energy — a figure unchanged since the height of the crisis (Figure 3).

[4] https://www.ipsos.com/en-uk/almost-nine-ten-britons-are-concerned-about-energy-prices

Figure 3: Higher energy costs are experienced by households across all incomes and remain a major public concern in England



Source: Family Resources Survey, 2023/24, Department for Work and Pensions; Ipsos UK

Exposure to high energy costs is uneven across England

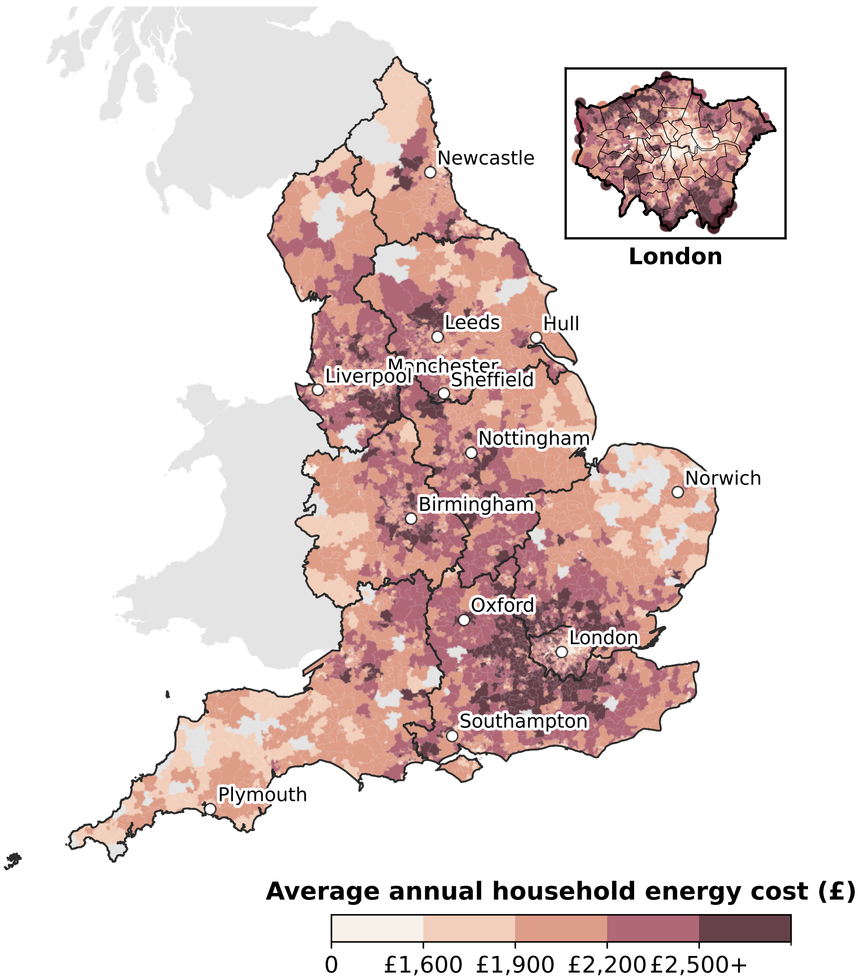
Although household energy prices are nationally regulated, the costs households face are far from uniform. Average bills depend not only on prices, but on how much energy households consume and how efficiently their homes convert energy into power.

As a result, some households face persistently high energy costs because they live in larger, older or less efficient homes, rely on more expensive heating systems, or have limited scope to reduce consumption. These differences reflect structural characteristics of housing rather than short-term behavioural choices alone.

Figure 4 illustrates this uneven exposure by mapping average household energy costs across England. Higher costs are concentrated across much of the North and Midlands, and parts of the South Coast, while lower average costs are more common in parts of the Southwest and East. There is also substantial variation within regions and cities.

This raises a key question: **if prices are broadly similar, why does its impact differ so sharply, and what does that imply for equitable energy policy?**

Figure 4: The burden of higher average household energy costs varies widely across England



Notes: Average annual household energy costs combine gas and electricity expenditure at MSOA level.
Energy consumption based on DESNZ sub-national statistics; prices follow Ofgem tariff caps.
MSOAs with insufficient records and areas outside England are shown in grey.

What drives differences in household energy costs?

To explore these drivers, we estimate a multivariate model that relates average household energy costs to building age and energy efficiency, dwelling characteristics, household composition and heating infrastructure, while controlling for regional differences. We aim to identify structural factors that are most strongly associated with high energy costs.

Results are summarised in Table 1. Three findings stand out.

1. **Housing energy inefficiency is a central driver of high costs.** Areas with a higher share of energy-inefficient homes (EPC bands D-G), face significantly higher annual energy costs, even after accounting for income and other housing characteristics. Poor insulation and inefficient heating systems amplify the associated increase of high prices, meaning that households in these homes pay more regardless of their income position.

2. **Housing form and household composition matter**. Older and larger dwellings, detached housing and areas with more large households all face higher energy costs, reflecting greater baseline energy needs. These factors help explain why some higher-income areas still experience high absolute cost: higher incomes often coincide with larger, more energy-intensive homes.
3. **Income shapes households' capacity to absorb energy costs rather than costs alone**. Higher incomes are associated with higher energy consumption and higher costs, but they also provide greater financial resilience. In contrast, areas characterised by lower incomes have far less scope to accommodate rising costs, particularly where poor housing efficiency or heating systems push cost upwards.

Table 1: Summary of Key Regression Findings

Structural factor (MSOA-level)	Modelled change in annual energy cost (per HH)
+10pp share of households with 4+ people	≈ +£170
+10% increase in median floor area of homes	≈ +£65-75
+10pp share of EPC D–G homes	≈ +£50–65
+10pp share of detached homes	≈+£50-60
+10% increase in household income	≈+£50-55
+10pp share of pre-1945 housing	≈+£15-20

Note: Effects are indicative averages and reflect associations rather than causal impact.

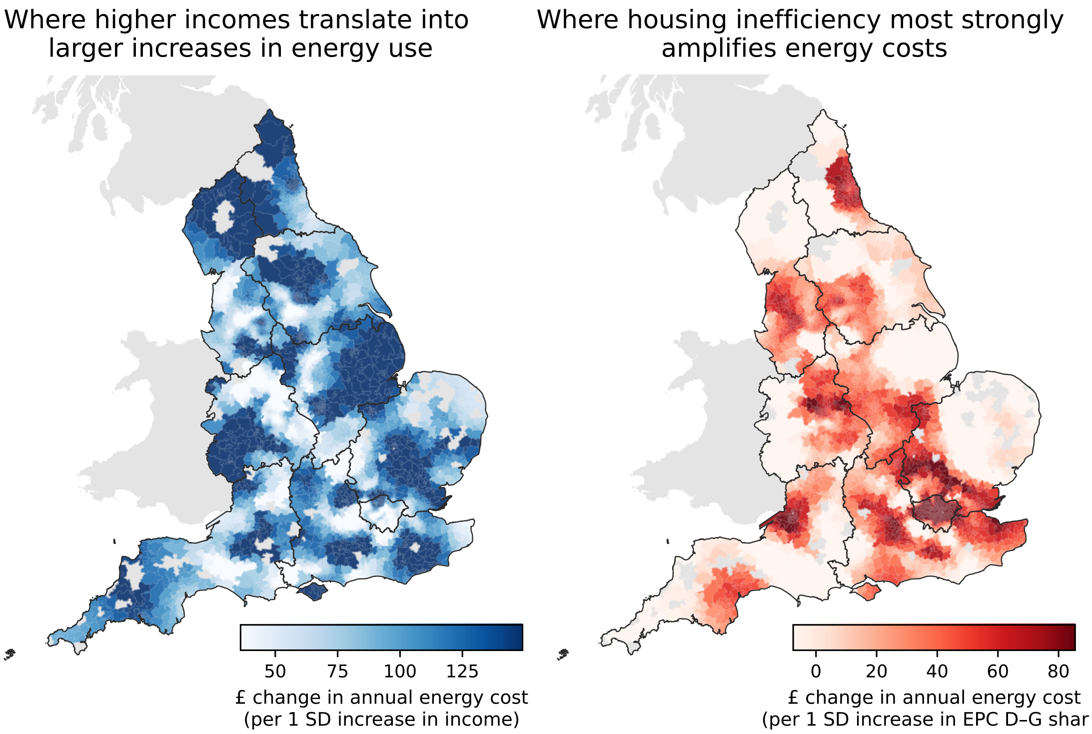
These findings explain why financial pressure may extend beyond the lowest-income groups. A substantial share of middle-income households report struggling with energy bills not solely because they consume unusually large amounts of energy, but because structural features expose them to persistently high costs. In equity terms, households with similar incomes can face different energy pressures depending on where and how they live.

Why place still matters

Even after accounting for income, housing characteristics and heating systems, some spatial variation in energy costs remains. This variation persists after controlling for regional differences, indicating finer localised differences such as housing stock composition, settlement patterns that shape how households experience energy prices.

Using a geographically weighted regression, Figure 5 shows how the influence of income and energy efficiency vary across England. In some areas, higher incomes are closely associated with higher energy costs, reflecting consumption linked to larger or more energy-intensive homes. In others, income plays a much weaker role. In contrast, the cost penalty associated with poor housing efficiency is uneven, with inefficient homes driving higher cost in some places but less so in others.

Figure 5: Mapping spatial heterogeneity in the mechanisms driving household energy costs



Note: Coefficients are locally estimated using geographically weighted regression (GWR) and clipped at the 12.5th and 87.5th percentiles for visual clarity.

Towards Equitable Policy: From Relief to Resilience

These findings spur the following policy considerations:

- **Moving Beyond Blunt Instruments:** While universal subsidies are politically expedient and provide immediate relief, they are blunt instruments that fail to address structural drivers. These measures treat symptoms, often subsidizing consumption for those who do not need it while failing to provide deep support for those in the most inefficient homes.
- **Efficiency as Long-Term Protection:** Sustained investment in housing energy efficiency, such as insulation and heating upgrades, remains the most effective long-term defense against structurally high prices. This is especially critical in areas where poor housing stock imposes “efficiency penalties” on residents regardless of their income.
- **Emphasis on Place-Based Targeting:** The spatial heterogeneity identified in this study suggests that national income thresholds alone are insufficient. To ensure support reaches those most exposed, policy must become “place-sensitive,” accounting for local housing conditions and structural vulnerabilities that income data alone might overlook.

As energy prices settle at a higher level, the challenge for policymakers is no longer how to smooth volatility, but how to prevent nationally regulated prices from deepening inequality, and to shape an energy system that is both efficient and equitable.

Technical Appendix

1. Study Objective

This study examines the structural drivers of domestic energy costs (electricity and gas) at the Middle Layer Super Output Area (MSOA) level in England. First, it identifies how housing characteristics, household composition, and heating systems are associated with variation in average annual household energy costs. Second, it assesses whether these relationships exhibit spatial dependence, indicating that some areas are systematically exposed to higher energy costs even after observable characteristics are controlled for.

The analysis is descriptive and explanatory rather than causal. By focusing on small-area averages, it highlights how nationally regulated energy prices translate into uneven local cost pressures through differences in housing stock, energy efficiency and household structure. The emphasis is on identifying structural sources of exposure and inequity, rather than estimating behavioural responses or causal treatment effects.

2. Data and Assumptions

2.1 Spatial unit analysis and data sources

MSOAs offer a balance between spatial resolution and data stability, avoiding the volatility associated with smaller geographies while preserving meaningful spatial variation. The table below summarizes variables retained in the preferred specification.

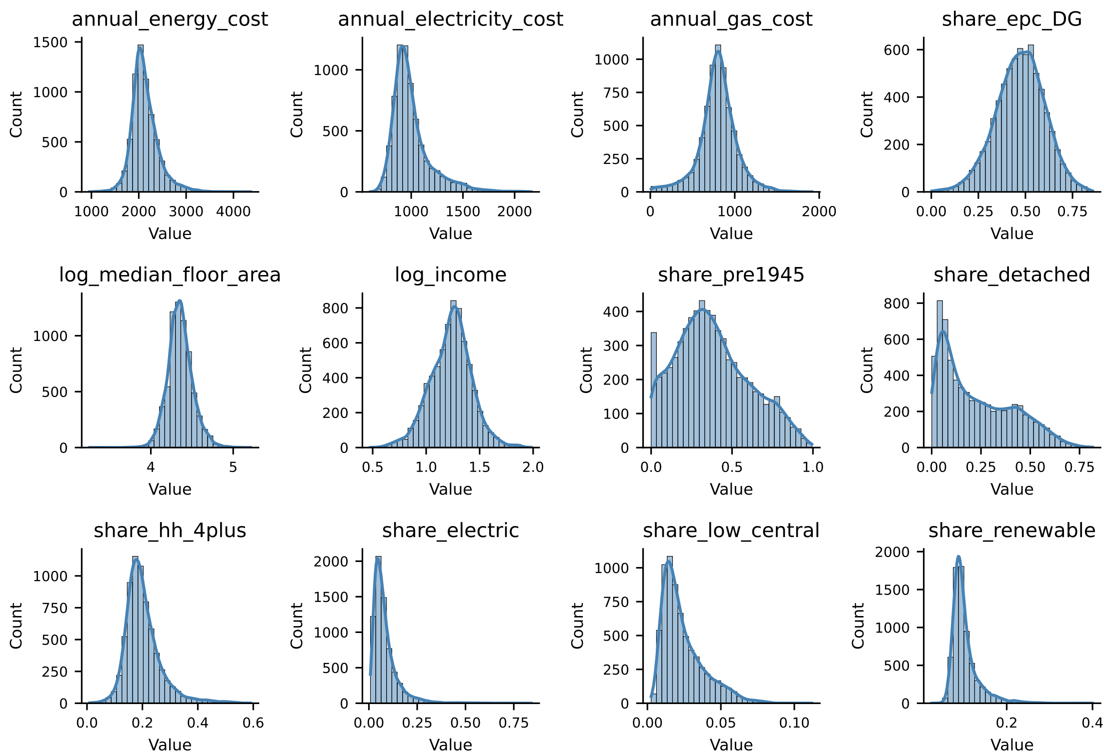
Variable	Source	Methodology & assumptions
Annual electricity consumption (kWh)	Department for Energy Security and Net Zero (2025a)	MSOA mean domestic electricity consumption per meter
Annual gas consumption (kWh)	Department for Energy Security and Net Zero (2025a)	MSOA mean domestic gas consumption per meter
Electricity & gas prices	Ofgem (2024)	National average price cap values (incl. VAT), Jan–Mar 2024
Annual energy cost (dependent variable)	Author	Electricity + gas consumption × unit prices + standing charges
Share of pre-1945 housing	Valuation Office Agency (2021)	Proxy for legacy housing inefficiency
Share of EPC D–G dwellings	EPC Register, DLUHC (2025)	Proxy for poor energy efficiency (2019–2025)
Median floor area (log)	EPC Register, DLUHC (2025)	Logged to address skewness
Median household income (log)	Office for National Statistics (2024)	Logged median household income at MSOA-level
Share of detached dwellings	Office for National Statistics (2022a)	Captures structural heat loss
Share of households with 4+ occupants	Office for National Statistics (2022b)	Captures household size
Heating type shares	Office for National Statistics (2022c)	Electric-only, solid/liquid fuels, renewable networks
Urban–rural indicator	Office for National Statistics (2022e)	Binary classification
Region	Office for National Statistics (2022d)	Region fixed effects

We assume that energy prices are nationally regulated and spatially uniform, reflecting Ofgem price caps. Spatial variation in observed energy costs therefore arises from differences in consumption, housing efficiency and heating systems rather than local price-setting.

2.2 Exploratory analysis of data variables

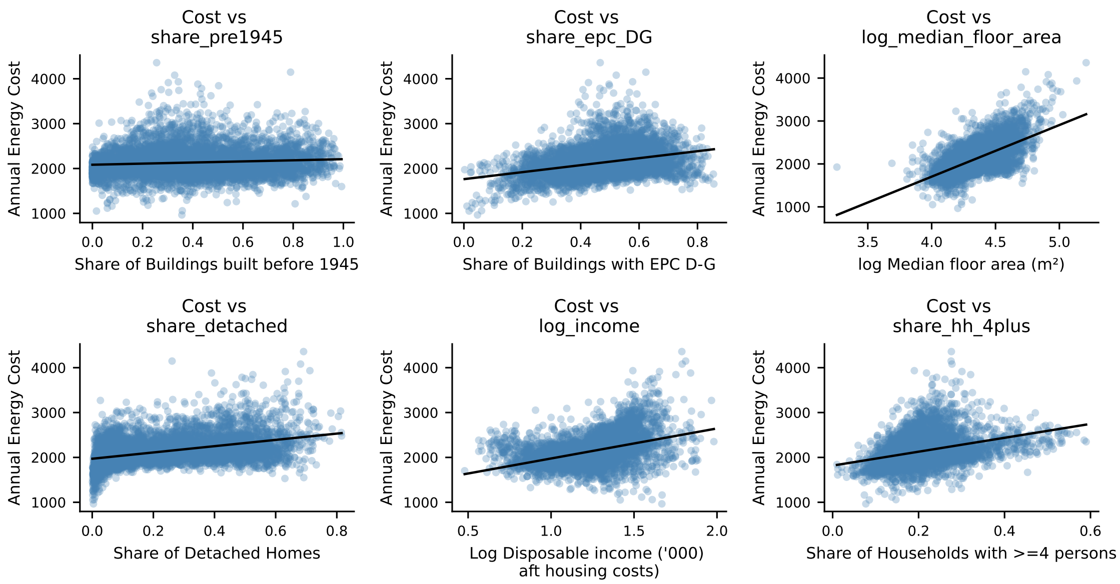
Exploratory analysis (Figure A1) highlights substantial right-skewness in electricity costs and total energy costs, driven by a subset of MSOAs with high electricity reliance and larger dwellings. As household income is also right-skewed, log-transformation is applied. Heating system variables are unevenly distributed across space but are retained, as they represent structurally distinct energy systems with implications for electricity demand and exposure to high prices.

Figure A1: Exploring the distribution of variables of interest



Exploratory plots of the dependent variable against key predictors (Figure A2) inform variable selection and specification.

Figure A2: Mapping bivariate relationships between energy cost and key predictors



3. Methodology and Model Specification

3.1 Construction of energy costs

Annual household energy costs are constructed by combining MSOA-level average electricity and gas consumption with national unit prices and standing charges. Electricity and gas costs are calculated separately and summed to obtain total average annual energy cost per household.

3.2 Regression framework

Ordinary Least Squares (OLS) regression is used as the primary modelling framework, due to its transparency and interpretability. Coefficients are interpreted as marginal associations with average annual household energy costs. All models are estimated with heteroscedasticity-robust (HC1) standard errors.

The preferred specification is:

$$\begin{aligned}\mathrm{EnergyCost}_i = \alpha &+ \beta_1\,\mathrm{Pre1945}_i + \beta_2\,\mathrm{EPC}_{D\text{-}G,i} + \beta_3\log(\mathrm{FloorArea}_i)\\ &+ \beta_4\log(\mathrm{Income}_i) + \beta_5\,\mathrm{Detached}_i + \beta_6\,\mathrm{HH}_{4+,i}\\ &+ \beta_7\,\mathrm{FuelMix}_i + \beta_8\,\mathrm{Urban}_i + \gamma_r + \varepsilon_i\end{aligned}$$

where i indexes MSOAs and γ⊠ denotes region fixed effects.

Variables capture four structural dimensions:

1. **Housing age and efficiency** (share pre-1945, share EPC D–G)
2. **Housing scale and form** (log floor area, share detached)
3. **Household composition and income** (log income, share 4+ households)

4. **Heating infrastructure** (fuel mix indicators)

Multicollinearity is assessed using variance inflation factors and remains within accepted thresholds.

4. Regression Findings

Across all specifications, **structural housing characteristics and household composition** emerge as the primary drivers of variation in annual household energy costs.

- A higher share of **energy-inefficient dwellings (EPC D–G)** and **pre-1945 housing** is consistently associated with higher energy costs, even after controlling for income and dwelling size. These effects remain stable across all model specifications, indicating that housing efficiency and age exert an independent influence on energy expenditure.
- **Dwelling size and housing type** are also strongly associated with energy costs. Larger median floor areas and a higher share of detached housing are linked to higher expenditure, reflecting greater baseline energy demand.
- **Household composition** also plays an important role. MSOAs with a higher share of households containing four or more persons exhibit substantially higher energy costs across all models, with this variable showing the largest coefficients throughout.
- The inclusion of **fuel mix variables** materially improves explanatory power, with the adjusted R^2 increasing from 0.572 to 0.713. Electric-only heating is associated with significantly higher energy costs, while solid and liquid fuels and renewables are associated with lower average expenditure.
- Adding **region fixed effects** further improves model fit (final adjusted $R^2 = 0.745$), likely capturing residual climatic variation and regional housing patterns, without materially altering the main coefficient estimates.

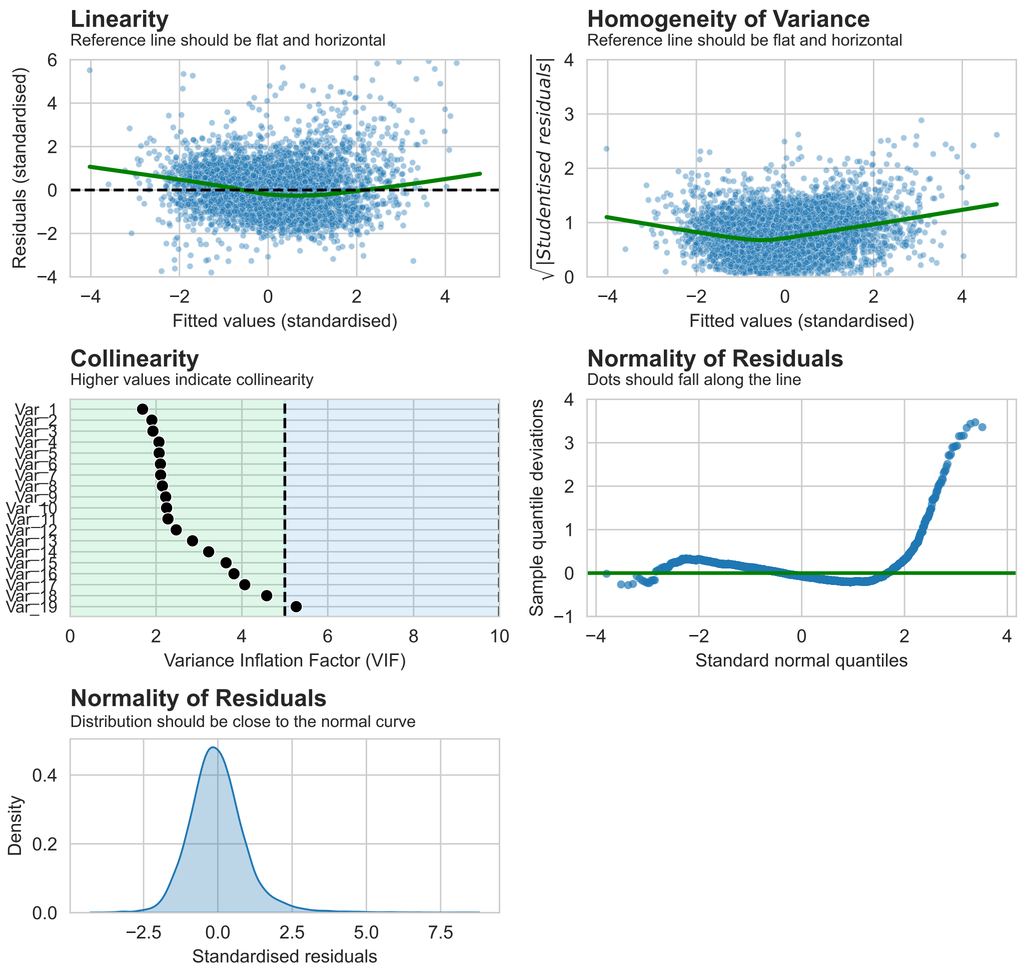
Summary of OLS Model Results

	Base	Fuel Mix	Urban/Rural	Region FE
const	-1708.679***	-2191.472***	-2134.568***	-1991.004***
	(149.537)	(172.332)	(176.690)	(177.240)
share_pre1945	54.063***	170.840***	166.743***	160.409***
	(12.978)	(11.807)	(11.890)	(11.429)
share_epc_DG	370.801***	469.468***	473.058***	485.204***
	(26.637)	(18.778)	(18.817)	(18.597)
log_median_floor_area	631.269***	770.978***	764.410***	664.267***
	(35.813)	(39.707)	(40.209)	(42.435)
log_income	412.632***	311.856***	315.012***	482.314***
	(14.647)	(13.942)	(13.930)	(22.162)
share_detached	251.286***	593.177***	581.973***	606.968***
	(24.442)	(22.842)	(22.981)	(22.990)
share_hh_4plus	1624.580***	1499.706***	1511.621***	1695.891***
	(38.536)	(40.416)	(40.598)	(45.159)
share_electric		499.663***	499.889***	585.689***
		(46.342)	(46.242)	(47.813)
share_solid_liquid		-1347.187***	-1416.278***	-1358.464***
		(44.446)	(44.056)	(44.788)
share_low_central		-1201.691***	-1147.186***	-453.648
		(311.190)	(310.575)	(314.565)
share_renewable		-1107.573***	-1153.494***	-1027.825***
		(105.118)	(105.588)	(112.285)
urban_dummy			-31.495***	-35.391***
			(7.782)	(7.313)
reg_East of England				11.032
				(7.778)
reg_London				-62.468***
				(12.890)
reg_North East				94.414***
				(9.057)
reg_North West				68.005***
				(7.288)
reg_South East				-3.277
				(7.670)
reg_South West				-122.950***
				(6.991)
reg_West Midlands				57.187***
				(6.870)
reg_Yorkshire				55.472***
				(7.092)
R-squared	0.572	0.713	0.714	0.745
R-squared Adj.	0.572	0.713	0.714	0.745
N	6791	6791	6791	6791

Standard errors in parentheses.
* p<0.1, ** p<0.05, *** p<0.01

Residual diagnostics (Figure A3) indicate satisfactory linearity and variance homogeneity, with mild right-skewness. Checks reveal a small number of high-cost MSOAs that tend to have larger dwellings and higher reliance on electricity.

Figure A3: Regression Diagnostics Dashboard - Adapted from (performance::check_model)



	VIF Summary	VIF	Plot_label
0	reg_North East	1.686154	Var_1
1	share_epc_DG	1.902158	Var_2
2	share_hh_4plus	1.927551	Var_3
3	reg_Yorkshire	2.067431	Var_4
4	reg_South West	2.071966	Var_5
5	reg_West Midlands	2.102305	Var_6
6	share_pre1945	2.106134	Var_7
7	urban_dummy	2.147526	Var_8
8	share_electric	2.224277	Var_9
9	reg_East of England	2.245763	Var_10
10	share_renewable	2.277739	Var_11
11	reg_North West	2.469844	Var_12
12	reg_South East	2.849354	Var_13
13	share_solid_liquid	3.225414	Var_14
14	share_detached	3.631050	Var_15
15	log_median_floor_area	3.815178	Var_16
16	log_income	4.066691	Var_17
17	share_low_central	4.577141	Var_18
18	reg_London	5.265254	Var_19

5. Unpacking spatial dependence via Spatial Error Model (SEM) and Geographically Weighted Regression (GWR)

Global Moran's I tests on OLS residuals show positive spatial autocorrelation ($I = 0.43$), indicating that neighbouring MSOAs share some unobserved characteristics influencing energy costs.

```
Moran's I value  =  0.43 with p = 0.001
```

Spatial Error Model (SEM)

To account for this, a Spatial Error Model (SEM) was estimated using maximum likelihood. The SEM identifies strong spatial correlation in the error term ($\lambda \approx 0.73$), consistent with possible omitted spatially structured factors such as housing typologies, retrofit histories or local infrastructure.

```
REGRESSION RESULTS
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SUMMARY OF OUTPUT: ML SPATIAL ERROR (METHOD = full)
---------------------------------------------------
Data set            :     unknown
Weights matrix      :     unknown
Dependent Variable  :annual_energy_cost             Number of Observations:        6791
Mean dependent var  :   2130.8608             Number of Variables   :          11
S.D. dependent var  :    294.3179             Degrees of Freedom    :        6780
Pseudo R-squared    :      0.6920
Log likelihood      : -42323.4933
Sigma-square ML     :  13329.1753             Akaike info criterion :   84668.987
S.E of regression   :    115.4520             Schwarz criterion     :   84744.043

------------------------------------------------------------------------------------
            Variable     Coefficient       Std.Error     z-Statistic     Probability
------------------------------------------------------------------------------------
            CONSTANT     -1796.30377        77.33022       -23.22900         0.00000
        share_pre1945      194.45965        10.24099        18.98837         0.00000
         share_epc_DG      408.82274        16.59709        24.63219         0.00000
log_median_floor_area       732.10715        19.44254        37.65490         0.00000
           log_income      175.13365        17.99068         9.73469         0.00000
       share_detached      704.82340        17.02771        41.39273         0.00000
        share_hh_4plus     1031.84763        42.01742        24.55761         0.00000
       share_electric      550.09246        36.92569        14.89728         0.00000
    share_solid_liquid    -1108.54704        33.07389       -33.51729         0.00000
     share_low_central     -747.51343       256.90902        -2.90964         0.00362
       share_renewable    -1183.19779        75.24002       -15.72564         0.00000
               lambda        0.73423         0.01009        72.76398         0.00000
------------------------------------------------------------------------------------
Warning: Variable(s) ['const'] removed for being constant.
================================ END OF REPORT =====================================
```

Notwithstanding, the findings are robust: **coefficient signs and magnitudes remain consistent with OLS estimates**. This suggests that while spatially clustered unobserved factors influence energy cost exposure, core structural relationships are correctly specified.

Geographically Weighted Regression

To further **explore spatial heterogeneity in coefficients**, Geographically Weighted Regression (GWR) was employed to examine how the impact of income and housing efficiency vary spatially. An adaptive bandwidth was selected via AICc.

Table 4: Geographically Weighted Regression (GWR) - Model Summary

	Metric	Value
0	Effective number of parameters (trace(S))	781.589
1	Degrees of freedom (n − trace(S))	6009.411
2	Sigma estimate	11105.445
3	Log-likelihood	-40850.569
4	AIC	83266.316
5	AICc	83470.474
6	BIC	88606.198
7	R^2	0.887
8	Adjusted R^2	0.872

	Variable	Coefficient	Std. dev.	Min	Mean	Max
0	Intercept	2207.98	220.54	750.35	2207.98	4028.94
1	Share pre-1945 homes	25.62	29.36	-112.75	25.62	145.98
2	Share EPC D–G homes	41.45	49.02	-86.38	41.45	247.65
3	Log median floor area	55.84	55.33	-89.08	55.84	300.52
4	Log income	89.19	51.33	-132.50	89.19	368.16
5	Share detached homes	148.40	192.09	-973.50	148.40	1634.11
6	Share households ≥4 persons	69.08	45.90	-123.66	69.08	229.57

Additional findings include:

- **Income-Driven Areas**: Higher energy costs align with income, suggesting consumption-led demand.
- **Efficiency-Driven Areas**: High EPC D–G coefficients indicate that poor housing quality drives costs regardless of household wealth.

While GWR reached an R^2 of 0.88, the elevated fit likely reflects GWR's inherent local overfitting and results serve an exploratory purpose rather than a formal refutation of the global model's performance.

6. Reflections and Limitations

This analysis is subject to several limitations. As an ecological study, it cannot capture within-area household heterogeneity or behavioural responses such as underheating. Data accuracy is also constrained by availability of EPC submissions which tend to be more sparse in rural areas, and retrofit history is not directly observed. Residual spatial clustering reflects genuine structural heterogeneity rather than model failure.

From an equity perspective, the results underline that exposure to high energy costs is shaped by place-specific housing conditions, not income alone. This reinforces the need for policy approaches that integrate housing efficiency and local context alongside income-based support.

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